MANAGING *Lolium perenne* L. (PERENNIAL RYEGRASS) IN A SUB-TROPICAL ENVIRONMENT IN KWAZULU-NATAL, SOUTH AFRICA

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I dedicate this work to my parents, Graham and Joan, who have instilled in me the desire to pursue goals, and to my wife Mandy, who is helping me to accomplish these.

DECLARATION

The research reported in this thesis comprises my own original work except for assistance acknowledged or where due reference is made in the text. This work has not been submitted for degree purposes to any other university.

F.R. Mckenzie
(M.Sc. Agric.)

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ABSTRACT

Lolium perenne L. (perennial ryegrass) generally fails to persist under the sub-tropical conditions of South Africa. Furthermore, little research data are available on how to manage this species locally. This study was designed to identify the management options, particularly with respect to grazing defoliation, which would help enhance the longevity of perennial ryegrass pastures. This was addressed by:

1) reviewing on-farm management practices of perennial ryegrass in KwaZulu-Natal;
2) conducting a detailed two-year field study of the effects of grazing frequency (HF, MF and LF = high, medium and low frequency, respectively) and intensity (HI, MI and LI = high, medium and low intensity, respectively), rotationally applied with the addition of a continuous grazing treatment (CG), on parameters linked to persistency. These included: tiller population dynamics, dry matter (DM) yield and quality, perennial ryegrass vigour, weed invasion and root development; and
3) examining effects of different levels of applied nitrogen (N) during the establishment year on various parameters linked to persistency. These included: tiller population densities, DM yield and quality, perennial ryegrass vigour, weed invasion and root development.

The review of on-farm management practices of perennial ryegrass growers in KwaZulu-Natal revealed that reasonably high rates of N application (e.g. 350 and 250 kg N ha^{-1} a^{-1} to perennial ryegrass as pure and clover-based stands, respectively) are important for pasture survival. However, a consistent distribution of the applied N is even more important (i.e. at least seven split applications of N onto pure stands of perennial ryegrass and five onto perennial ryegrass-clover). In terms of grazing management, the period of absence of animals from the pasture during summer was identified as the most important grazing variable affecting pasture survival (i.e. $\geq$ 21 days). Also, the length of the period of occupation by animals should be as short as possible, particularly during summer (i.e. $\leq$ 3 days). Paying careful

attention to summer irrigation is also an important variable contributing to pasture survival. Grazing intensity was not highlighted as an important contributor to pasture survival.

In terms of tillering potential, DM yield and quality (cellulose dry matter disappearance and herbage N) and perennial ryegrass vigour, perennial ryegrass followed definite seasonal trends. These were highest during autumn and spring and were lowest during the mid to late summer period. Perennial ryegrass was most susceptible to general sward degradation through poor management during the mid to late summer period when the danger from weed invasion is greatest and its growth potential, vigour and tillering abilities are lowest. Within these seasonal periods, grazing defoliation produced marked effects. In terms of tiller survival, DM yield, plant vigour, reduced weed invasion and root production, treatments incorporating low frequency grazing (e.g. LFLI and LFHI) generally out-performed ($P \leq 0.05$) those incorporating high frequency grazing, irrespective of the intensity (e.g. HFHI, HFLI, and continuous grazing (CG)). The defoliation treatment incorporating medium frequency and intensity (MFMI) (currently the recommended defoliation strategy for perennial ryegrass) was also out-performed in many instances ($P \leq 0.05$) by the low frequency treatments (e.g. LFHI and LFLI).

During the establishment year, increasing levels of applied N increased ($P \leq 0.05$) perennial ryegrass DM yields and herbage quality. Models predicting the response of DM yield and quality to applied N suggest linear responses up to 720 kg N ha^{-1} a^{-1}. Further refinement of such models and the inclusion of animal production parameters is recommended. Maximum ($P \leq 0.05$) tiller population densities occurred at applied N levels of 480 kg ha^{-1} a^{-1}. Perennial ryegrass vigour increased ($P \leq 0.05$) with increasing levels of applied N up to 480 kg ha^{-1} a^{-1}, but individual tiller vigour decreased. Increasing levels of applied N up to 360 kg ha^{-1} a^{-1} suppressed ($P \leq 0.05$) weed tiller densities. Increasing levels of applied N (up to 600 kg ha^{-1}) increased ($P \leq 0.05$) the root organic matter (OM) per unit volume of soil in the top 5 cm of the soil and decreased root OM per unit volume in the 10 - 20 cm soil depth category.

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CHAPTER 1

INTRODUCTION

1.1 General background

For many years, *Lolium multiflorum* Lam. (Italian ryegrass) has formed the basis of intensive dairy systems in South Africa, and is now increasingly used for both fat lamb and beef production. Italian ryegrass is high-yielding and produces an excellent quality forage (Bredon & Stewart 1978; Eckard 1994). Despite its popularity amongst farmers, however, the necessity to re-establish this pasture annually constitutes a major disadvantage. Increased mechanisation costs have initiated a search for perennial grass species which can fulfil the same role in these livestock production systems, but which do not require annual re-establishment. At present, establishment costs for Italian ryegrass (including seed, lime, fertilizers, irrigation, machinery costs and interest on operating capital) are in excess of R3 300 per hectare (Combud 1994). It is surprising then, that the use of a temperate perennial species, such as *Lolium perenne* L. (perennial ryegrass), has been limited on farms in South Africa. In this regard, a problem with perennial ryegrass has been its lack of persistence under grazing (du Plessis 1986).

Recently, a number of new varieties of perennial ryegrass have emerged as possible replacements for annual ryegrasses, but these too have generally failed to persist in local production systems. Indications are that, in its second year, perennial ryegrass may decline to 60% of its production from the first year. Reasons for non-persistence seem to revolve around the use of inappropriate grazing programmes under local conditions, especially during summer. The effects of frequency and intensity of grazing on the yield and especially the persistence of perennial ryegrass has received no research attention in South Africa. It is, therefore, essential to pursue studies that will identify management options which will help enhance the longevity of perennial ryegrass.

It is interesting to note that the failure of perennial ryegrass to persist is not unique to South Africa. Fulkerson *et al.* (1993) report that perennial ryegrass lacks persistence under the sub-tropical conditions of Australia, where swards last up to three years, or four years, only under exceptional circumstances.

Previous research under temperate conditions has demonstrated that the system of management applied to perennial ryegrass pastures has a marked effect on species survival and performance, and ultimately influences the yield of dry matter (DM) obtained annually from these pastures (Brougham 1960). Local temperatures are considerably higher than those to which the species is adapted, and in South African systems, nitrogen (N) fertilizer often replaces clover N which helps support the growth of this species in temperate climates. If perennial ryegrass is to successfully replace the annual ryegrasses in local production systems, management strategies will need to be designed which will improve its persistence in such systems. These will need to be based on an understanding of the influence of, and interaction between, grazing intensity and grazing frequency. In addition, both the persistence and regeneration of tiller populations in this species under local climatic conditions will need to be improved.

1.2 Justification

The only information available on management of perennial ryegrass for South African conditions is contained in reports prepared by Goodenough *et al.* (1991), Eckard (1993) and Eckard (1994). In addition, all information supplied in Goodenough *et* *al.* (1991) and Eckard (1993) is based primarily on research principles developed under temperate conditions in non-African countries, and a few interviews held with local farmers who plant perennial ryegrass. A point highlighted in these reports is that much uncertainty remains concerning the growth pattern and herbage yield potential of perennial ryegrass in different climatic areas. The information contained in Eckard (1994) is the only recent, locally acquired, formal information currently available on perennial ryegrass in South Africa.

Local seed merchants supplying farmers with perennial ryegrass seed have tested this species under local conditions. However, these tests involve classical plant introduction and small plot cutting trials, none of which progress to full scale field tests under grazing (Perennial ryegrass evaluation pamphlets, 1984 - 1994, Roodeplaat Grassland Institute, Private Bag X9059, Pietermaritzburg, 3 200, South Africa). The perennial ryegrass pastures tested under these conditions do not persist for more than two years (D.C.W. Goodenough 1994, personal communication, Roodeplaat Grassland Institute, Private Bag X9059, Pietermaritzburg, 3 200, South Africa). The need, therefore, remains for scientific research on how to manage perennial ryegrass under grazing in order to enhance its survival under sub-tropical conditions.

Interestingly, a few farmers in the South African province of KwaZulu-Natal have succeeded in retaining perennial ryegrass for six years, and sometimes longer, before their pastures require re-establishment (personal observation). Unfortunately, the reasons for such success, and more importantly the reasons for the multitude of failed pastures, have never been quantified.

The response and growth patterns of perennial ryegrass in relation to climatic conditions have, however, been extensively researched in temperate countries (e.g. Mitchell 1953; Brougham

1958; Garwood 1969; Evans 1971; Thomas & Norris 1977; 1981; Davies & Thomas 1983; White 1990). For example, Thomas and Norris (1977) demonstrated that seasonal patterns of leaf DM production by vegetative tillers was largely controlled by temperature. A review of research on the effects of climate on growth and survival of perennial ryegrass in temperate climates highlights the lack of information to describe perennial ryegrass growth under sub-tropical climatic conditions in South Africa.

Much information also exists on the nature of re-growth after defoliation (by cutting and grazing) of perennial ryegrass pastures under temperate conditions (e.g. Edmond 1958b; Brougham 1960; Edmond 1962; 1963; 1964; Evans 1971; 1973; Davies 1974; Tainton 1974; Thomas 1980; Korte 1986; Korte *et al.* 1984; 1985; 1987; Weeda & During 1987; Thom 1991). In addition, the pattern of tillering in this species has also received considerable attention in both New Zealand (e.g. Soper 1958; Hunt & Brougham 1967; Korte *et al.* 1982; Hongwen *et al.* 1990; Thom 1991; Thom & Bryant 1993) and the United Kingdom (e.g. Davies & Thomas 1983; Curll & Wilkins 1985; Hume 1991; Swift *et al.* 1993). This information helps form the basis of grazing management programmes for perennial ryegrass in temperate environments. Thus, there is a need to establish effects of grazing frequency and intensity on re-growth and tillering patterns of this species under sub-tropical conditions because this will allow objective grazing programmes to be formulated.

The author believes that measurements of sward components (such as individual tiller dynamics in grazing experiments, herbage DM yield and quality, plant vigour, weed invasion and root production) will improve our mechanistic understanding of the effects of different grazing programmes on perennial ryegrass. More importantly, an understanding of these sward components will help towards developing improved grazing management strategies for perennial ryegrass under sub-tropical conditions.

1.3 Objectives

To address the dearth of data relating to the management of perennial ryegrass in South Africa, and particularly regarding ways of enhancing the persistence of this species, three separate studies were undertaken. The first addressed the effects of grazing management on various sward components over two years. The second studied the short-term effects of applied N on various sward components. For the third study, a comprehensive mail survey of the management practices of perennial ryegrass farmers in KwaZulu-Natal was conducted.

1.3.1 Grazing trial

It was hypothesized that changes in the population density, which in turn are brought about by changes in the birth and death rates of tillers as a direct result of grazing defoliations, would govern the persistence of perennial ryegrass. The objectives addressed by this project included:

(1) establishing the effect of contrasting grazing frequencies and intensities during spring, summer, autumn and winter on the morphological development and survival of a population of perennial ryegrass tillers;

(2) establishing the relative importance of tillering at different times of the year in grazed swards by determining seasonal patterns of tiller appearance and death, and survival of tillers appearing in different seasons;

(3) determining in which season a particular grazing defoliation treatment will stimulate pasture regeneration through lateral tillering;

(4) testing the effect that different grazing intervals and intensities have on the herbage DM production and quality of perennial ryegrass;

(5) testing the effects of grazing management on the vigour of perennial ryegrass and its subsequent ability to out-compete potentially invasive weeds; and

(6) examining the influence of contrasting grazing frequencies and intensities on root production at varying depths in the soil profile.

1.3.2 Nitrogen trial

Contrasting views on the influence of applied N on the survival of perennial ryegrass lead to the establishment of a second field trial. This trial was designed to test the short-term (12 months) effects of applied N on various growth parameters of perennial ryegrass. The objectives addressed by this study included:

(1) establishing whether or not there are any specific levels (both lower and upper) of applied N at which there are marked changes in perennial ryegrass tiller densities;

(2) quantifying the effect of contrasting levels of applied N on the production of reproductive and aerial tillers in perennial ryegrass;

(3) determining the effect of various N levels on DM production and quality of the pasture; and

(4) establishing the effect of N application rate on the vigour of perennial ryegrass and its subsequent ability to out-compete potentially invasive weeds.

1.3.3 Mail survey of perennial ryegrass growers in KwaZulu-Natal

Some farmers in the KwaZulu-Natal province of South Africa have managed perennial ryegrass successfully for six years or longer before having to re-establish the pasture (personal observation). Many farmers, on the other hand, experience difficulty in achieving acceptable production levels even during the second year after establishment. It was, therefore, decided to conduct an inventory and analysis of the various perennial ryegrass management practices currently being used by farmers in KwaZulu-Natal. The objectives of this mail survey included:

(1) addressing general questions concerning perennial ryegrass

in KwaZulu-Natal such as: suitable climatic areas, area currently under perennial ryegrass, livestock enterprises utilizing perennial ryegrass, and utilization and related production issues;

(2) identifying possible reasons in the management of perennial ryegrass (particularly grazing management) for failure of this pasture to persist under sub-tropical conditions in KwaZulu-Natal; and

(3) identifying the management practices that have allowed perennial ryegrass to persist under sub-tropical conditions in KwaZulu-Natal.

1.4 Thesis format

Due to the nature of the project, comprising three separate studies, it was possible to consider the various aspects of the studies as individual chapters. Each chapter comprises sub-sections which commence with an introduction followed by the experimental procedure adopted. Results are then discussed and conclusions drawn both on the merits of the techniques and analyses conducted, and are related to other published literature. These chapters are followed by a concluding chapter which draws on the overall findings of the preceding chapters to formulate management recommendations. The thesis thus comprises five chapters including: an introductory chapter, three result reporting chapters, and a general discussion and concluding chapter.

Ideally, the mail survey of perennial ryegrass farmers in KwaZulu-Natal should have preceded the field trials, however, this was not possible over the three year time span given for the project. While the mail survey was conducted during the third year of the project, it was decided to report these results before those of the field trials as these formed a good review in the absence of locally published data on perennial ryegrass.

CHAPTER 2

A REVIEW OF CURRENT MANAGEMENT OF PERENNIAL RYEGRASS IN KWAZULU-NATAL, SOUTH AFRICA

2.1 Introduction

Perennial ryegrass has traditionally been a grass pasture species reserved for use in temperate environments, to which the species is adapted (Gibbs Russell *et al*. 1990). It is not surprising, therefore, that difficulty is experienced in cultivating this species under sub-tropical or tropical conditions. South Africa is not unique in the difficulties encountered with the persistency of this species within its intensive livestock enterprises in sub-tropical environments. Fulkerson *et al*. (1993) reported similar problems with perennial ryegrass in Australia. For these reasons, pasture advisors and agricultural extension personnel have tended to down-play the potential value of perennial ryegrass in South Africa. They frequently cite reduced production levels in the pasture's second and subsequent years after establishment, to substantiate their argument.

It is interesting to note, however, that there are farmers in South Africa who have reported that their perennial ryegrass has survived six years or longer, before requiring re-establishment (personal observation). Alternatively, there are those farmers who do indeed experience survival problems with such pastures within two years of establishing them. Given the current situation where useable research knowledge in South Africa is lacking, it is important to establish what management practices are being employed by the more successful farmers using perennial ryegrass. Such information will have a two-fold purpose. Firstly, in practical terms, more objective advice than is currently on offer can be made available to farmers. Secondly, the information gleaned from farmers can be used to generate questions and hypotheses which in turn can form the basis of future research.

2.2 Study area

The study was confined to the province of KwaZulu-Natal which is situated on the eastern seaboard of southern Africa. KwaZulu-Natal is well suited to pasture intensification mainly because most of the rangeland is 'sour' (Bartholomew 1985). Since KwaZulu-Natal is a summer rainfall region, intensive livestock production systems rely on irrigated temperate pastures for high quality forage during autumn, winter and spring. In KwaZulu-Natal, 4 502 692 ha of land is devoted to commercial agriculture, of which 3 097 947 ha are rangelands and 175 722 ha are under cultivated pastures (Anon 1991).

In KwaZulu-Natal, rainfall is confined largely to the summer months and varies from as little as 320 mm a^{-1} in the drier regions to 2 353 mm a^{-1} at the foot of the Drakensberg mountains (Anon 1991). Corresponding mean temperatures for these rainfall extremes are 23 and 13 °C, respectively (Phillips 1973). However, it is not necessarily the mean, but rather the range of temperatures which is most important to the survival of plants. Many plant species are excluded from areas which are apparently suitable for them because of temperature extremes, especially of cold (Tainton 1981). Temperature and rainfall conditions in KwaZulu-Natal, and how these relate to altitude, are summarized by Phillips (1973) who described the Bioclimatic regions of KwaZulu-Natal (Figure 2.1).

At altitudes below 450 m (Coastal Lowlands) the climate is capable of supporting a tropical type of evergreen forest, thicket or woodland. These areas have high annual rainfall (mean of 850 - 1400 mm) and high temperatures (annual mean of 20 - 22 °C) with only occasional mild frosts. Annual mean temperatures

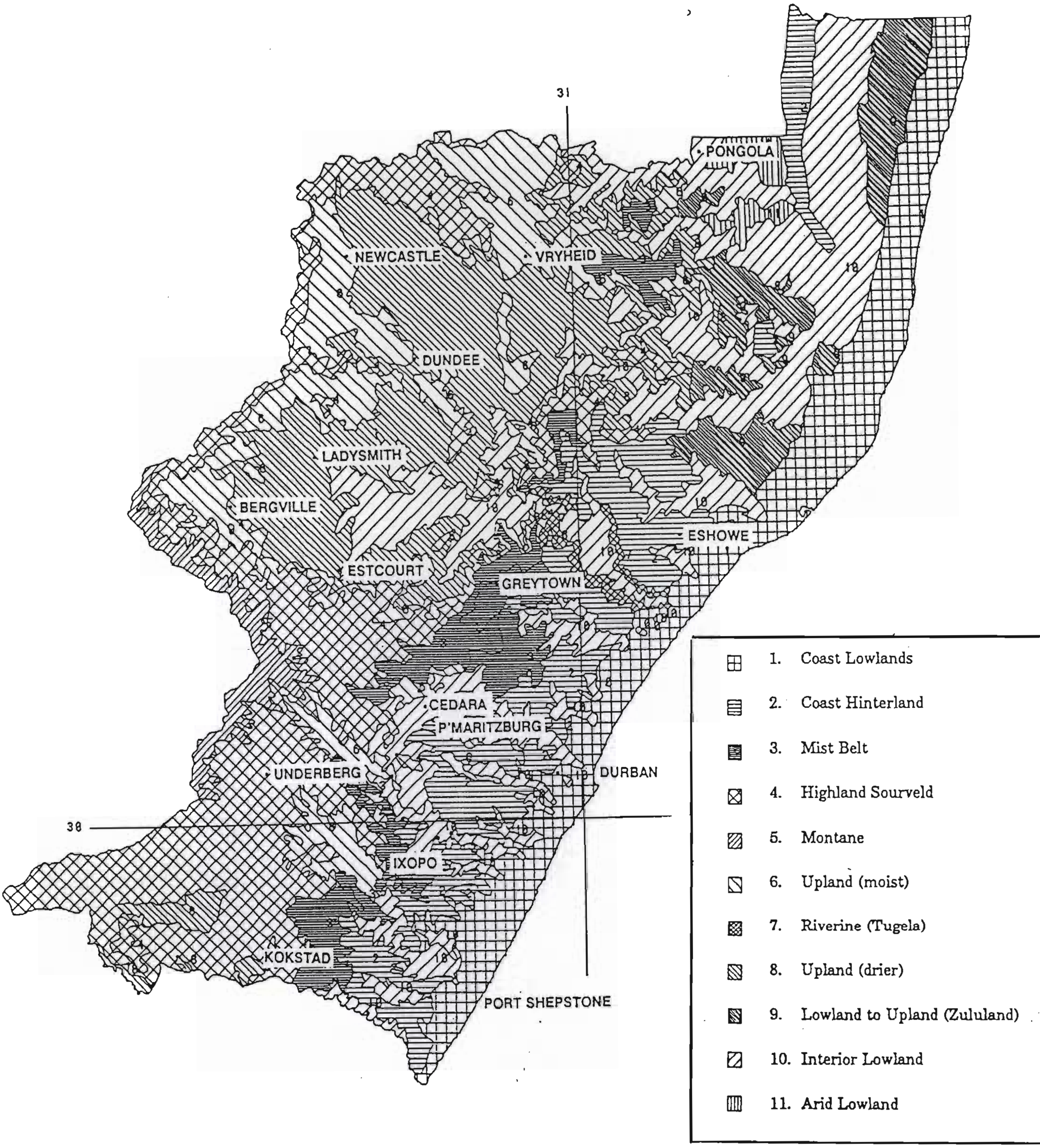


Figure 2.1 The Bioclimatic regions of KwaZulu-Natal (Phillips 1973).

similar to these are found inland at altitudes of 450 - 900 m (Riverine and Lowland to Upland Bioclimatic regions, respectively). However, the temperature range here is greater than that experienced at the coast. Frost-free conditions in these regions allow a semi-deciduous vegetation type to develop. At altitudes of 900 - 1 400 m (Mist Belt) annual temperature means are lower (16 - 18 °C) than at the coast, and moderate to severe frosts are encountered during the winter months. The vegetation supported by this climate is decidedly less tropical than at lower altitudes. The higher lying regions at 1 400 - 1 950 m (Highland to Submontane) have relatively low mean annual temperatures (13 - 15 °C) and experience moderate to severe frosts for greater lengths of time than the Mist Belt. This area is capable of supporting evergreen and semi-deciduous forest. At altitudes of 1 950 - 3 400 m (Montane), snow may fall during any month of the year. Here the vegetation is composed largely of temperate grass species and fynbos shrubs (vegetation found also in the western Cape winter rainfall region). It is thus evident that KwaZulu-Natal encompasses wide ecological diversity.

Adding to this diversity is the effect that soils have on the vegetation. Generally, the lower lying more arid regions are characterised by eutrophic (base rich) soils, being subject to less leaching during their development than the higher rainfall acid leached soils (dystrophic) (Tainton 1981). In the higher lying, more humid regions, the soils in KwaZulu-Natal are highly weathered and nutritionally poor (Miles 1986).

2.3 The questionnaire

Given the lack of local literature on perennial ryegrass, it was decided to survey farmers in KwaZulu-Natal who have utilized or are currently utilizing this pasture. This was achieved by means of a mail survey.

The decision to use a mail survey, as opposed to a personal or telephone survey, was to take advantage of the simple administrative procedure associated with mail surveys and to save on manpower, time and money. In addition, a mail questionnaire can canvass a wide (regional or national) sample and still be controlled from a central location (Filion 1978). Scott (1961) found that mail questionnaires were generally as accurate as those obtained from interviews. In designing the questionnaire, suggestions by Dillman (1978) and Filion (1978) were adhered to. These included: pre-testing the questionnaire for clarity and ease of answering; using covering letters to explain the usefulness and importance of the study; and assuring participants of their anonymity and pointing out that participation was voluntary.

The primary objectives of the questionnaire were to:

(1) address general questions concerning perennial ryegrass in KwaZulu-Natal such as: suitable climatic areas, area currently under perennial ryegrass, livestock enterprises utilizing perennial ryegrass, and utilization and related production issues;

(2) identify possible reasons in the management of perennial ryegrass (particularly grazing management) for failure of this pasture to persist under sub-tropical conditions in KwaZulu-Natal; and

(3) identify the management practices that have allowed perennial ryegrass to persist under sub-tropical conditions in KwaZulu-Natal.

In order to achieve these primary objectives, questions were carefully constructed to ensure that the questionnaire was reasonably short, easy to understand, and complete.

A list of potential perennial ryegrass farmers in KwaZulu-Natal was compiled after approaching all the agricultural extension personnel in KwaZulu-Natal. These extension personnel then forwarded the names and addresses of such farmers within their areas. The major seed distributors of perennial ryegrass were also contacted to help provide an even more comprehensive list of perennial ryegrass growers in KwaZulu-Natal.

Prior to mailing the questionnaire, a letter (preliminary notice) was sent to prospective participants at the beginning of January 1994 (Appendix 2.1). This letter outlined the need for the study by placing it within the context of the research on perennial ryegrass currently being conducted at the University of Natal.

Approximately two weeks after dispatching the preliminary notice, the questionnaire, together with a covering letter, was mailed (mid January 1994). The covering letter (Appendix 2.2) explained the importance and usefulness of such a study. In addition, it assured participants of their anonymity in the survey and reminded them that participation was voluntary.

The questionnaire (Appendix 2.3) consisted of five sections and a total of 32 questions. The sections comprised of the following subheadings: (A) General considerations, (B) Climatic data, (C) Pasture production, (D) Pasture utilization, and (E) General comments.

The first section (General considerations) was designed to obtain information on current areas established to perennial ryegrass, whether this pasture has been established with a companion legume (e.g. clover) and what livestock enterprises utilize it.

The second section (Climatic data) addressed the question: in which Bioclimatic regions can perennial ryegrass be grown successfully?

The third section (Pasture production) comprised various aspects of pasture management and related production issues. It included questions on soil fertility (phosphorus (P), potassium (K) and soil acid saturation), N fertilizer programmes, pasture longevity, irrigation scheduling, and estimated herbage production.

The fourth section (Pasture utilization) called for a detailed examination of how the pasture is utilized, particularly with respect to the grazing management currently adopted by farmers.

The final section of the questionnaire (General comments) allowed farmers to express their own views regarding possible advantages/disadvantages of perennial ryegrass relative to annual ryegrass cultivars. It also provided an opportunity for farmers to make any further comments that they deemed relevant. It should be noted at this stage that while the term 'annual' ryegrass is often used to refer to *Lolium rigidum*, for the purpose of this chapter cultivars of Italian ryegrass (*Lolium multiflorum*) will be referred to as 'annual' ryegrass. This is because the term 'annual' is increasingly being used amongst farmers when referring to Italian and Westerwold ryegrass cultivars (Eckard 1994).

2.4 The survey

A total of 150 questionnaires (together with covering letters and a stamped self-addressed envelope) were mailed on 12 January 1994.

A reminder was mailed on 15 February 1994 (Appendix 2.4). The reminder included a covering letter, a second copy of the questionnaire, a stamped self-addressed envelope and a form on which the participant could request a summarised copy of the survey results. This reminder served three purposes. Firstly, it thanked those respondents who had already replied to the survey and asked them to ignore the rest of the reminder. Secondly, participants who had not replied were asked to please do so at their earliest convenience. Lastly, it again emphasised the importance of the findings of such a study and provided an opportunity for each participant to request a summary of the main findings of the survey by returning the enclosed request form (Appendix 2.5). Despatching a reminder has been found to be an effective technique to maximise the rate of returns. It suggests to the addressee that a reply is important (Filion 1978).

2.5 Data analysis

The first step in analyzing the returned questionnaires was to edit replies and code the data. Frequency distributions and graphs of the responses to different questions were generated using a spreadsheet.

Further analyses were conducted using the Statistical Package for Social Sciences (SPSS) programme (Norusis 1990). This allowed correlation and regression analyses to be conducted so that potential variables affecting pasture survival could be identified. It must be noted at this stage, that unless otherwise stated in the text, data from both current (81% of the respondents) and previous (19% of the respondents) growers of perennial ryegrass were used in all analyses.

2.6 Results and discussion

2.6.1 Questionnaire return

Of the 150 questionnaires dispatched, 84 (56%) were returned. After withdrawing unfilled (12) questionnaires, the useable (i.e. those containing analyzable data) questionnaires were reduced to 72 (48%). This rate of return compares favourably with review findings and a mail survey conducted by Oellermann (1994), where return rates ranged from 31 to 54%.

The reminder that was mailed one month after the first questionnaire, yielded 15 questionnaires (10%) of the useable 72 returned. The extra effort expended in sending out reminders, therefore, proved to be worthwhile. The additional questionnaires returned after the reminder was sent were identified from the original questionnaires by a small identifying mark on the first page. Apart from this mark, they were identical to the original questionnaire.

2.6.2 General considerations

This section summarizes responses to general questions by illustrating frequencies as a percentage of the total respondents answering a question (Figures 2.2, 2.3 & 2.4).

It is interesting to note that the majority (64%) of perennial ryegrass farmers plant this species in association with clover (Figure 2.2). This is presumably to take advantage of the reduced N inputs with a legume-supplemented pasture, and to improve the general quality of the forage (Hoglund *et al.* 1979). In this regard it is not surprising then that only 15% of perennial ryegrass farmers planted this pasture as a pure stand, while 21% planted perennial ryegrass both alone and in combination with clover (Figure 2.2). It is possible that, in the absence of reliable research-based advice, farmers that used both options (i.e. perennial ryegrass without and with clover) were experimenting for themselves to determine whether a clover-based pasture is better in their situation than a pure stand of perennial ryegrass. In fact, Goodenough *et al.* (1991) suggest that farmers located in areas where perennial ryegrass has not been successful, should establish a small area to evaluate its suitability and management requirements before establishing larger areas. This they presumably do as a pure perennial ryegrass pasture.

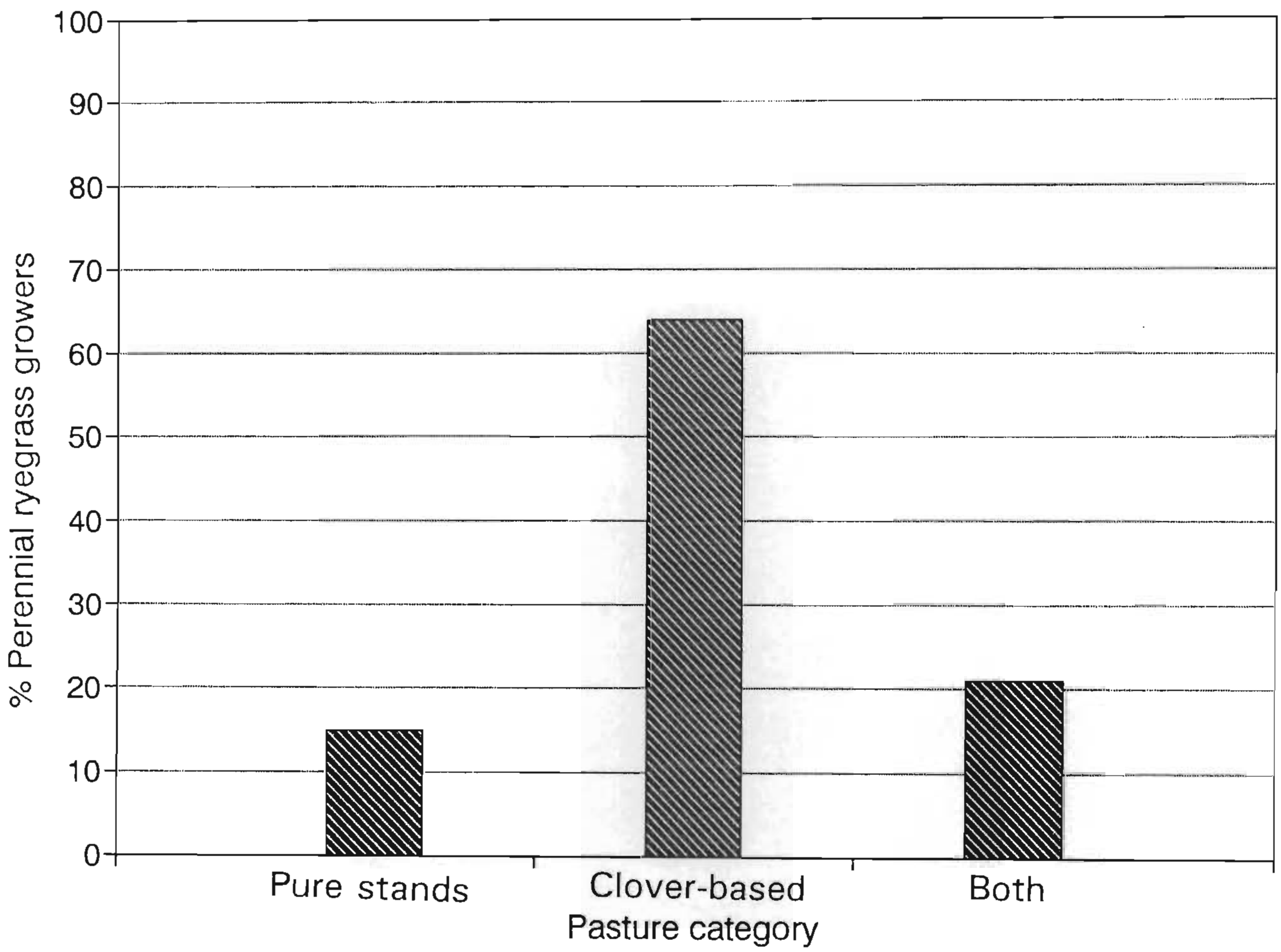


Figure 2.2 The proportion of perennial ryegrass farmers in KwaZulu-Natal planting this species as a pure stand, with clover or both.

In terms of livestock enterprises based on perennial ryegrass, dairy systems were reported to be the most popular for both pure stands of perennial ryegrass and perennial ryegrass-clover in KwaZulu-Natal (59 and 75%, respectively) (Figure 2.3). This was followed by fat lamb production (21 and 15%) while beef utilized the lowest proportion (20 and 10%) (Figure 2.3). No farmers reported basing more than one livestock enterprise on perennial ryegrass pastures (i.e. there were no combinations of livestock enterprises within one farming unit). Traditionally, dairy systems in KwaZulu-Natal have always been the major users of perennial ryegrass pastures (as pure or clover-based stands) (Eckard 1994). However, with an improvement in the knowledge on how to manage perennial ryegrass under sub-tropical conditions, it is believed that this species may well gain popularity for use in beef and fat lamb production systems.

Considering areas established to perennial ryegrass on individual properties, the most frequent area categories were in the region of 7.5 ha (most often as a pure grass pasture) (31%) and > 15 ha (most often mixed with clover) (38%), respectively (Figure 2.4). Farmers appeared to be more confident in establishing large areas to perennial ryegrass if the pasture was clover-based. This may suggest that including clover in a perennial ryegrass pasture is conducive to a more successful pasture (in terms of production, quality and longevity). Estimated areas established to pasture (calculated by multiplying the number of individuals who responded by the midpoint of the area range) are also presented (Figure 2.4). In the case of the area category > 15 ha, actual values cited by respondents were used. It should also be noted that only current growers of perennial ryegrass in KwaZulu-Natal were used in this exercise. The total area established to pure stands of perennial ryegrass in KwaZulu-Natal, based on the survey, is estimated at 295 ha. The total for perennial ryegrass clover-based pastures is estimated at 853 ha. The total area currently under perennial ryegrass cultivation in KwaZulu-Natal

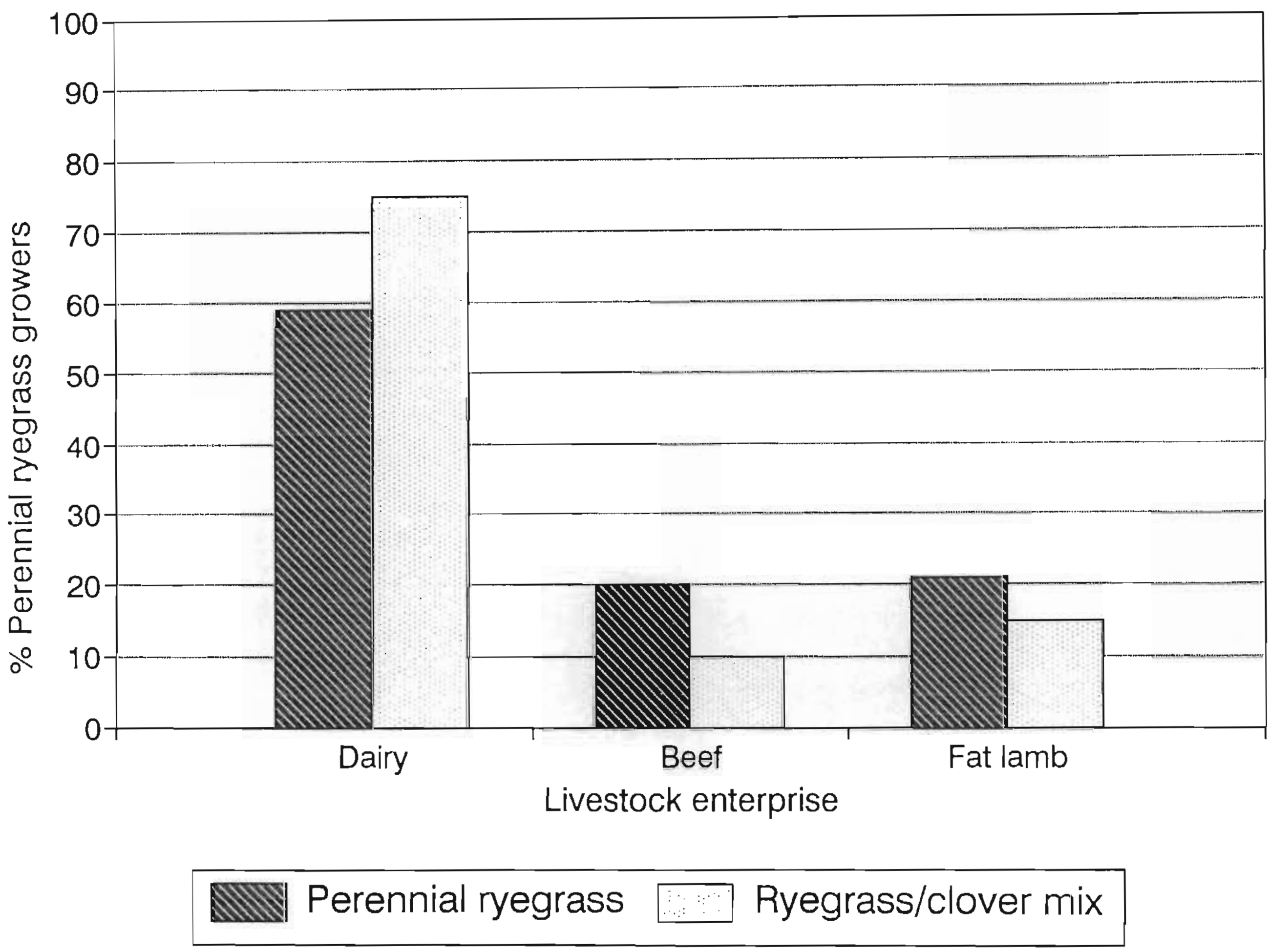


Figure 2.3 The proportion of perennial ryegrass farmers in KwaZulu-Natal using this species as a pure or clover-based stand for different livestock enterprises.

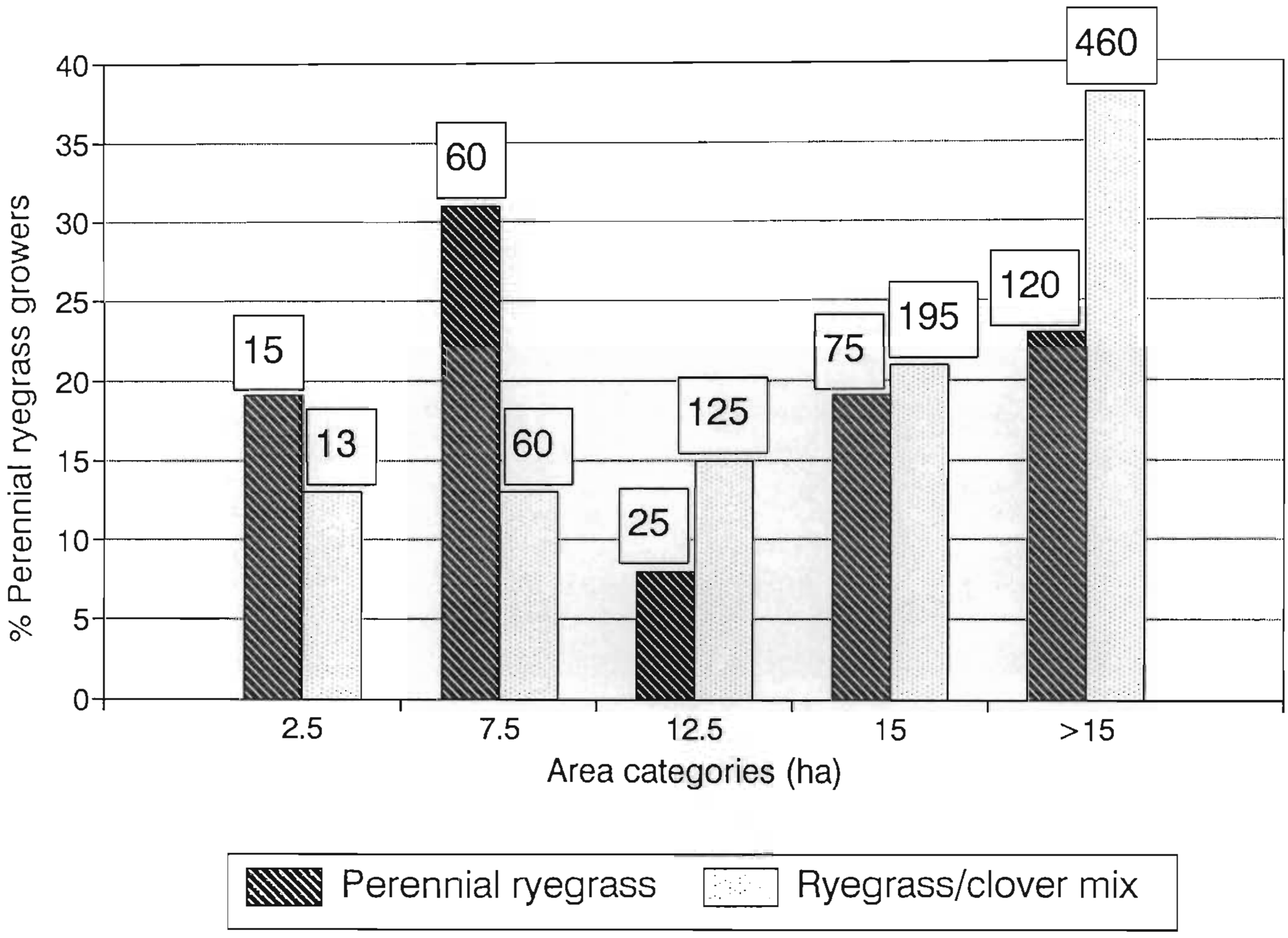


Figure 2.4 The proportion of farmers planting different areas (ha) of perennial ryegrass, as pure or clover-based stands, in KwaZulu-Natal (total estimated area (ha) planted in each class is given above each bar).

is, therefore, estimated at 1 148 ha. It is stressed that not all perennial ryegrass farmers responded to the questionnaire (i.e. the useable response was 48%), and some may not have been sampled. This is, therefore, considered an extremely conservative estimate of the total area currently under perennial ryegrass cultivation in KwaZulu-Natal.

2.6.3 Climatic distribution

Climatic areas in KwaZulu-Natal which appear not to be suited to perennial ryegrass cultivation include Bioclimatic regions 1 (Coast Lowlands), 2 (Coast Hinterland), 9 (Lowland to Upland), 10 (Interior Lowland) and 11 (Arid Lowland) (Figure 2.5). Since KwaZulu-Natal is a summer rainfall region and intensive temperate pastures such as perennial ryegrass require irrigation, particularly during autumn, winter and spring, it is unlikely that rainfall is a factor excluding perennial ryegrass cultivation from these regions. It is more likely that high mean annual temperatures (20 to 23 °C) and periodic extreme high summer temperatures (> 40 °C) (Phillips 1973; Tainton 1981) exclude these areas from perennial ryegrass cultivation.

Climatic areas that are currently (note that currently implies that previous perennial ryegrass growers were excluded from this exercise) the most popular for perennial ryegrass cultivation are Bioclimatic regions 3 (Mist Belt) and 4 (Highland Sourveld). These regions account for 28 and 40% of the farmers planting perennial ryegrass, respectively (Figure 2.5). The mean annual temperatures for these regions are only 16 to 18 °C and 13 to 15 °C, respectively (Tainton 1981).

Other climatic areas in KwaZulu-Natal currently supporting perennial ryegrass are Bioclimatic regions 5 (Montane), 6 (Upland (moist)), 7 (Riverine) and 8 (Upland (drier)). The proportions of perennial ryegrass currently established in these Bioclimatic

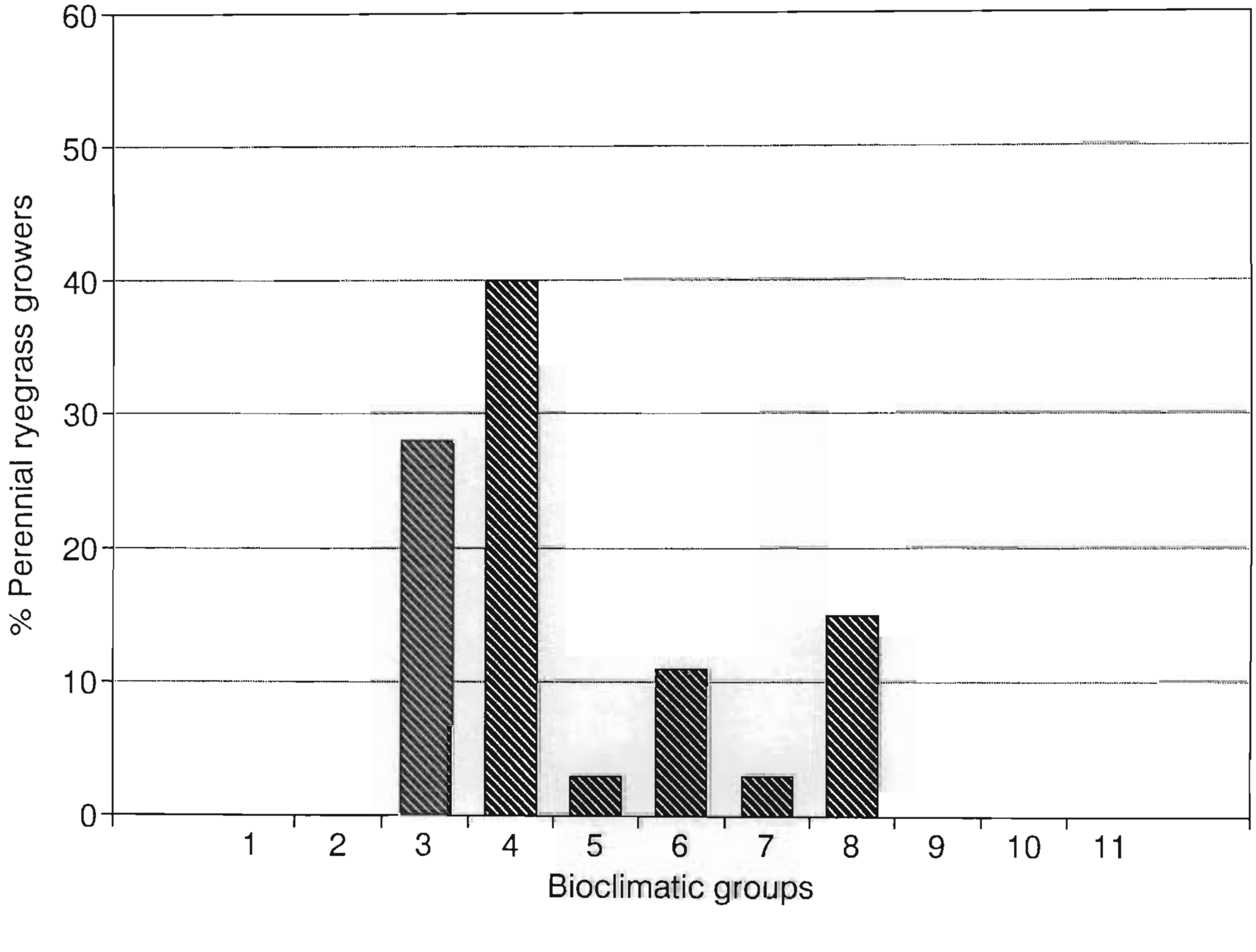


Figure 2.5 The proportion of perennial ryegrass farmers cultivating this pasture in different Bioclimatic regions of KwaZulu-Natal.

regions are 3, 11, 3 and 15%, respectively (Figure 2.5). Corresponding mean annual temperatures are 13, 16 to 18, 17 to 22 and 17 to 19 °C, respectively (Tainton 1981). It is surprising to note that perennial ryegrass is successfully being cultivated by two respondents (3%) in the Riverine region where mean annual temperatures range from 17 to 22 °C. One of these respondents re-establishes perennial ryegrass every two years, while the other has successfully maintained perennial ryegrass, without re-establishing, for more than six years. A situation such as this stresses the need to examine reasons why certain growers of perennial ryegrass are successful under sub-tropical conditions, relative to others.

2.6.4 Pasture production and utilization

Results of the survey clearly showed that the most popular season for establishing perennial ryegrass (as pure or clover based stands) is autumn (86%) rather than spring (14%) (Figure 2.6). This is presumably to avoid potential weed infestation which commonly occurs in spring established pastures (Booysen 1981) and to avoid exposing young developing plants to extreme early summer temperatures. Alternatively, 17% of farmers in KwaZulu-Natal have either tried or currently establish perennial ryegrass during both autumn and spring (Figure 2.6), perhaps as a test to establish which season is best in their situation.

Application rates of N ranged from 50 to > 400 kg N ha^{-1} a^{-1} (Figure 2.7). It must be noted that the mid points of the ranges used in the questionnaire are reported on. A rate of 350 kg N ha^{-1} a^{-1} was most widely used on pure stands of perennial ryegrass (44%), while 250 kg N ha^{-1} a^{-1} was most widely used on perennial ryegrass-clover (33%) (Figure 2.7). This application rate of 250 kg N ha^{-1} for perennial ryegrass-clover corresponds with the level suggested by Eckard (1994), who advised that 250 kg N ha^{-1} a^{-1} be applied as five top dressings between April and October (when clover is less active than perennial ryegrass).

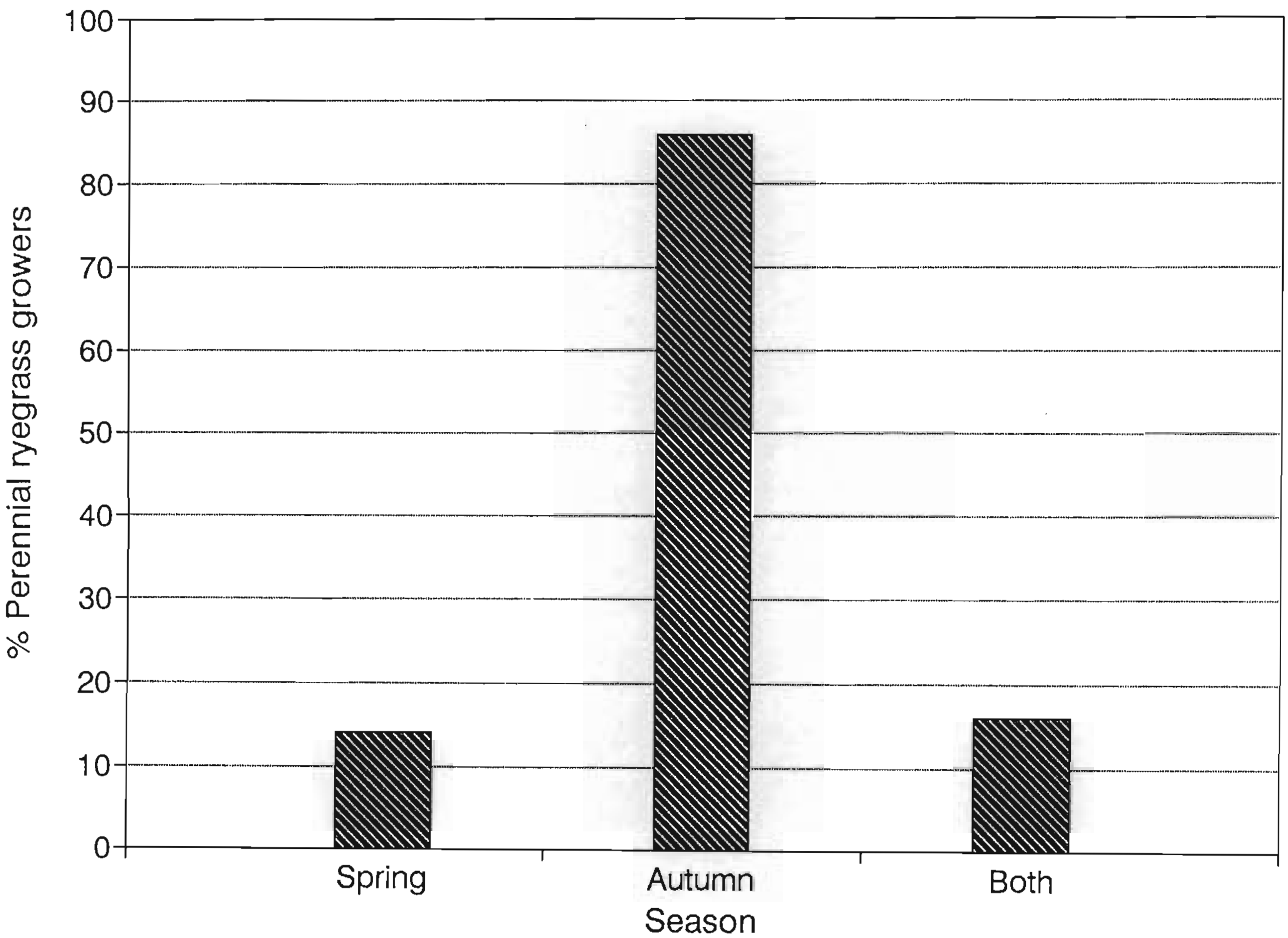


Figure 2.6 The proportion of farmers establishing perennial ryegrass as pure or clover-based stands in spring and autumn (or both spring and autumn).

The lower N levels (50 to 250 kg N ha^{-1} a^{-1}) were generally favoured for perennial ryegrass-clover, presumably due to the contribution of fixed N by the legume component. It was surprising to find that 8 and 5% of farmers planting perennial ryegrass-clover applied the high levels of 400 and > 400 kg N ha^{-1} a^{-1}, respectively (Figure 2.7). It is well known that high applications of N to such pastures is detrimental to the survival of the legume component (Frame & Boyd 1986; Frame & Newbould 1986; Rangeley & Bolton 1986; Eckard 1994). Chestnutt and Lowe (1970) found that even with applications above 150 kg N ha^{-1} a^{-1}, the clover component decreased relative to the grass component.

The number of applications of N ranged from one to > 11 (on an annual basis) for both pure stands of perennial ryegrass and perennial ryegrass-clover. Of these, three split applications were the most popular (24%) for pure stands of perennial ryegrass, while four split applications were the most favoured (17%) for perennial ryegrass-clover (Figure 2.8). Surprisingly, for pure stands of perennial ryegrass, the majority of farmers (56%) applied only between two and five (inclusive) split applications of N (Figure 2.8). This is in spite of the fact that pastures, and especially those intensively cultivated, require a continuous supply of N to maintain production and enhance longevity (Allison 1966).

The majority of perennial ryegrass farmers in KwaZulu-Natal (73% of those planting pure stands of perennial ryegrass and 60% of those planting perennial ryegrass-clover) reported a production decline during the second year after establishment. Potential reasons for this are addressed by means of correlation and regression analysis using SPSS (see section 2.6.5).

A total of 71% of farmers planting pure stands of perennial ryegrass implemented pasture regeneration, with sod-seeding (i.e.

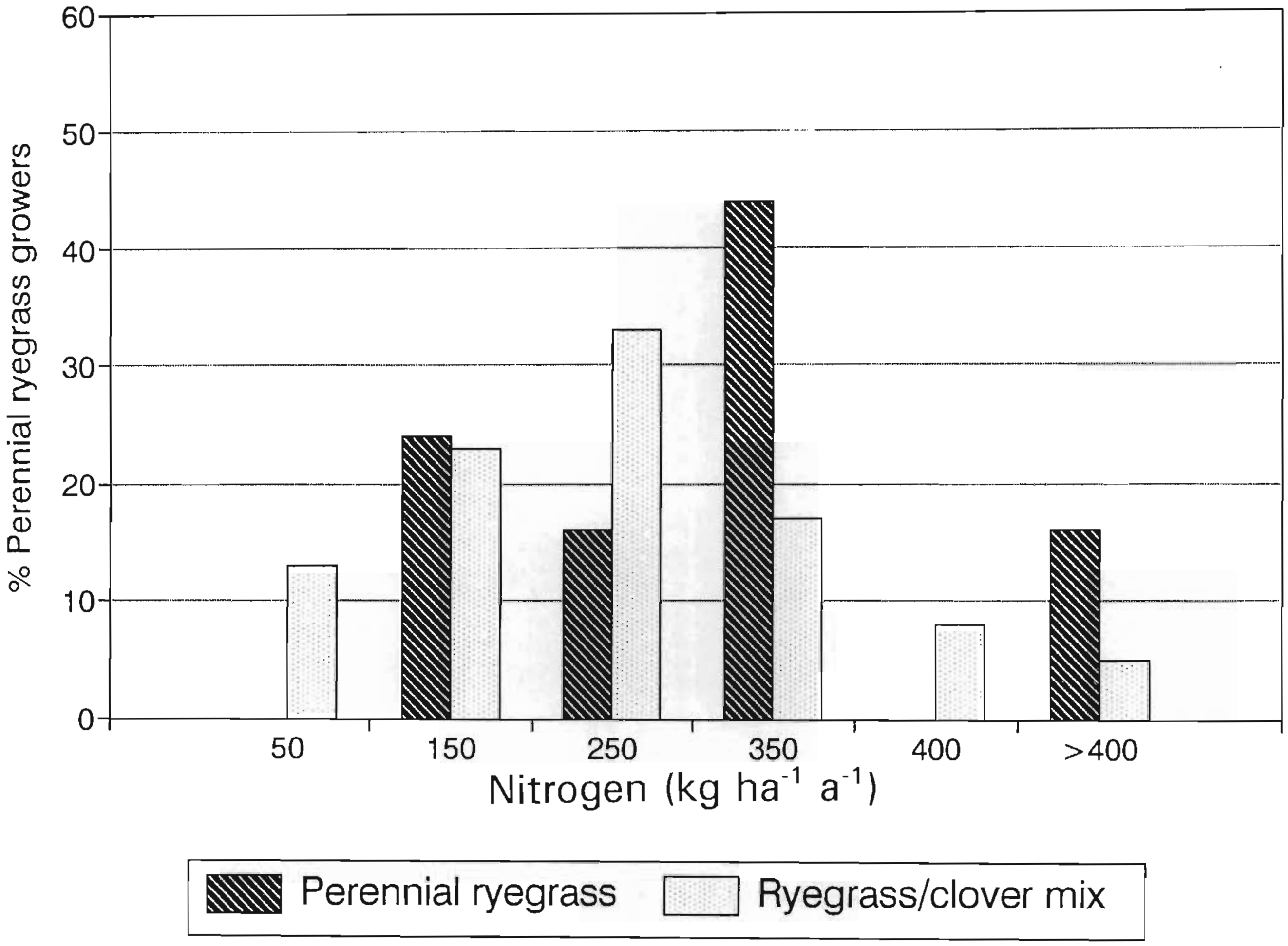


Figure 2.7 The proportion of farmers in KwaZulu-Natal applying different annual applications of N to perennial ryegrass (as pure or clover-based stands).

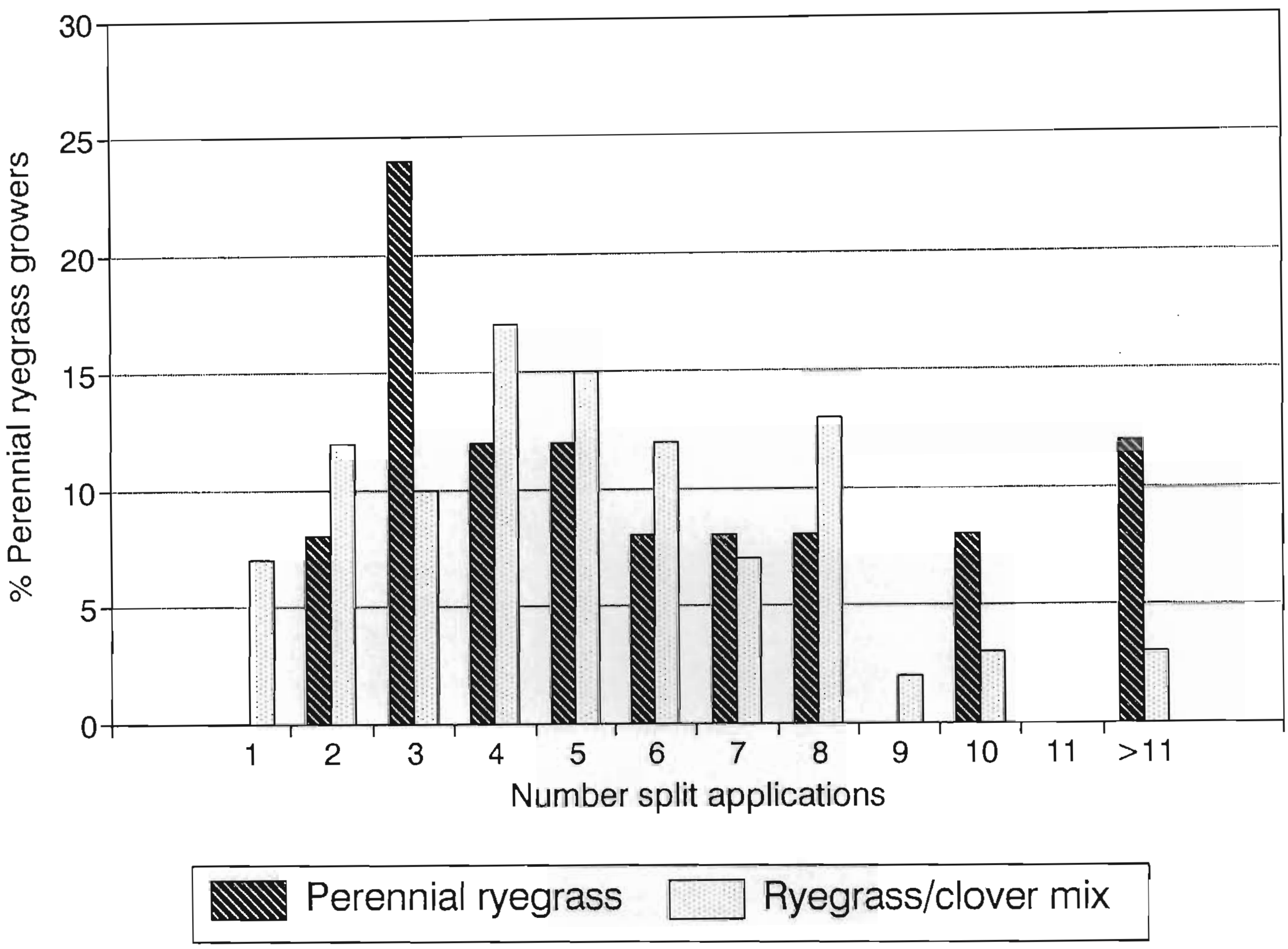


Figure 2.8 The proportion of farmers in KwaZulu-Natal applying various split applications of N to perennial ryegrass (as pure or clover-based stands).

direct drilling) being the most popular option (34%) (Figure 2.9). Seventy seven per cent of farmers planting perennial ryegrass-clover also reported practising pasture regeneration, with sod-seeding again being the most popular option (41%) (Figure 2.9).

Up to 40% of farmers planting pure stands of perennial ryegrass implemented pasture regeneration during the second year after establishing the pasture, while 32% did so during the third year. In contrast, the greater proportion of farmers (34%) planting perennial ryegrass-clover implemented pasture regeneration only during the third year, and 25% did so only during the fourth year (Figure 2.10). This suggests that pasture renovation increases the time before re-establishment is required. These results also appear to indicate that pastures containing clover remain productive for longer than do those without clover. This observation is supported by data on how long a pasture survives before requiring complete re-establishment (Figure 2.11). Of the farmers planting pure stands of perennial ryegrass, the highest proportion (27%) re-established after three years. Relative to this, the greatest proportion of farmers (31%) planting perennial ryegrass-clover, re-established their pastures after four years (Figure 2.11). It was noted that 12 and 5% of farmers planting perennial ryegrass (as pure and clover-based stands, respectively) maintained their pastures for more than six years (Figure 2.11). Possible reasons for these observations are examined later (see section 2.6.5).

When farmers were asked whether they would accept the option of having to re-establish perennial ryegrass (without or with clover) biennially, provided only a negligible drop in production would be experienced in year two, the majority (71 and 72%, respectively) responded positively. This serves to highlight the seriousness of reduced pasture production during a pasture's

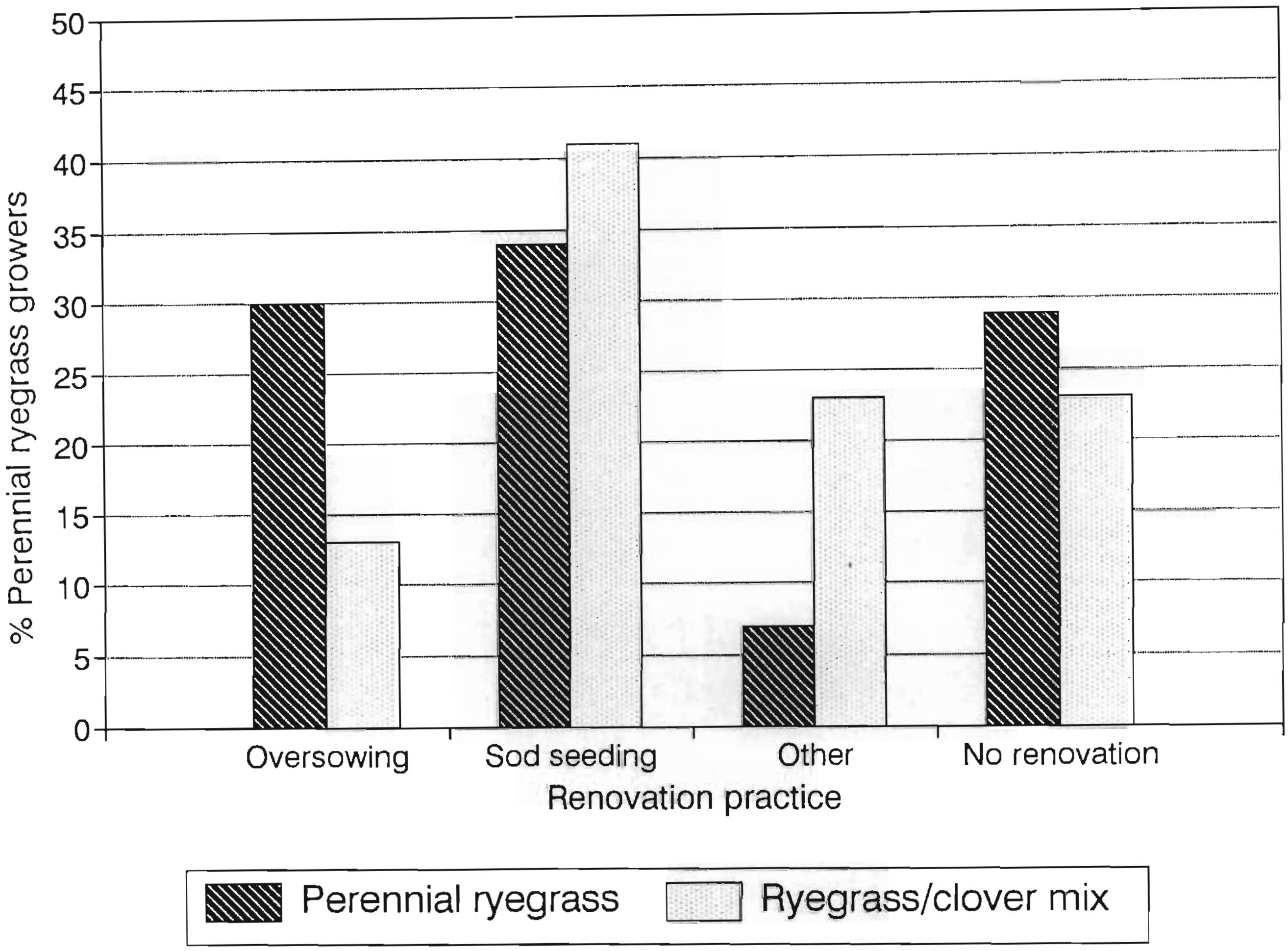


Figure 2.9 The proportion of farmers in KwaZulu-Natal practising pasture regeneration on perennial ryegrass (pure and clover-based stands). The 'other' category incorporates pasture aeration (to address soil compaction problems).

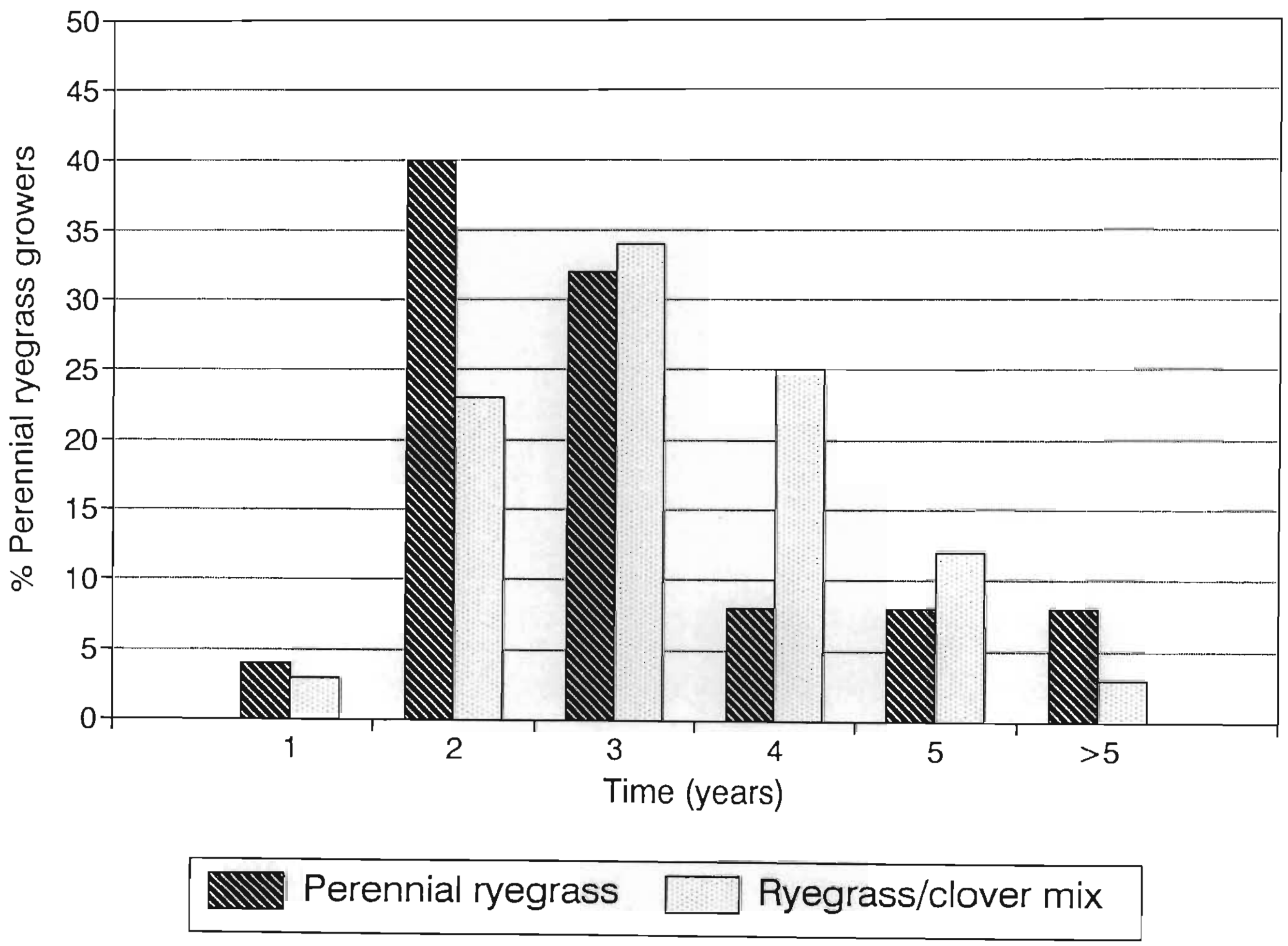


Figure 2.10 The proportion of farmers in KwaZulu-Natal implementing pasture regeneration after a certain time (years) on perennial ryegrass (pure and clover-based stands).

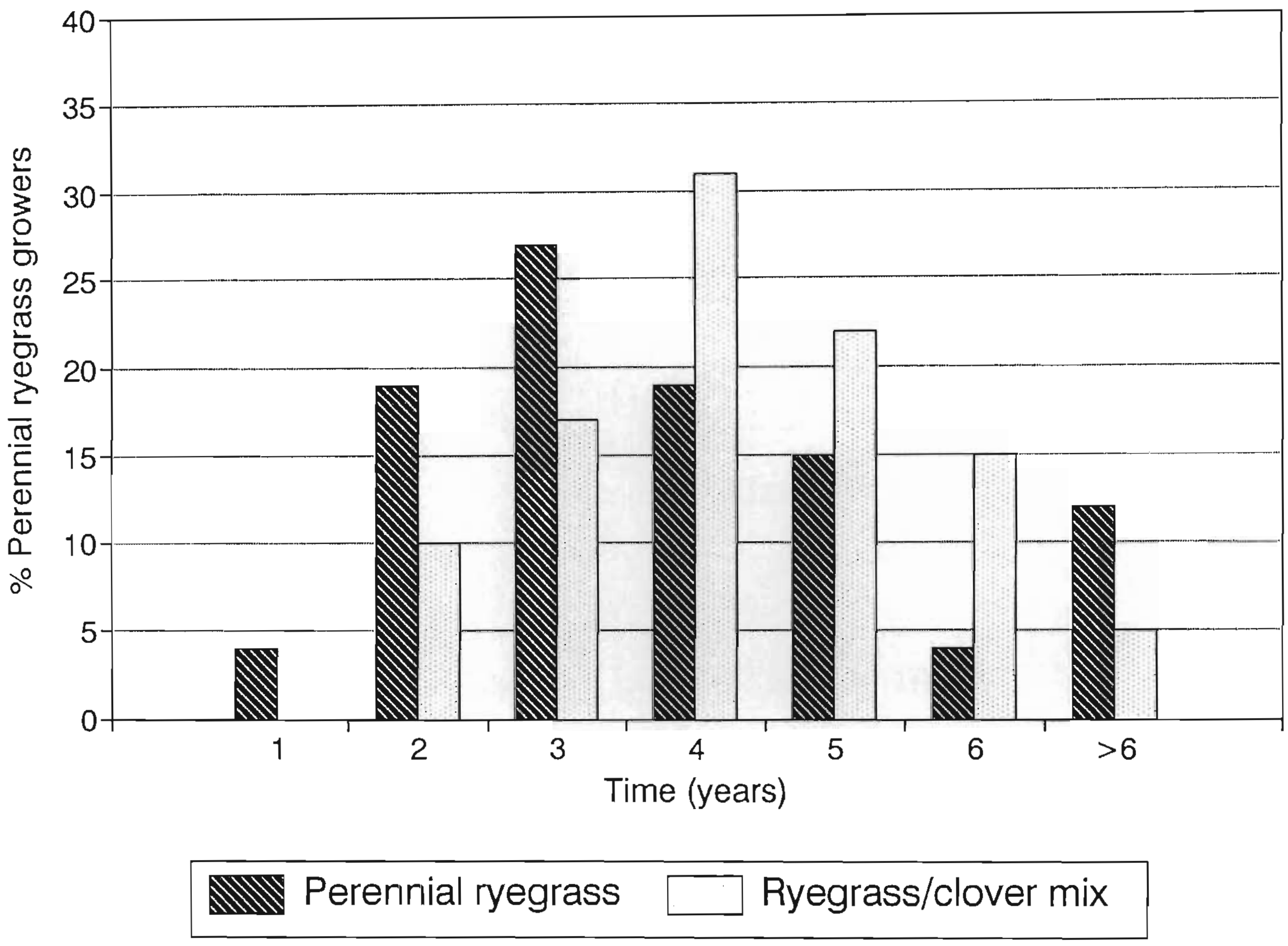


Figure 2.11 The proportion of farmers in KwaZulu-Natal completely re-establishing perennial ryegrass (pure and clover-based stands) after a certain time (years).

second year, as perceived by farmers.

The actual DM yield estimates for the first, second and third year for perennial ryegrass (as pure and clover-based stands, respectively) are presented (Table 2.1). It should be noted that for the first year's yield estimate, mid points of the ranges depicted in the questionnaire were used. For the second and third year's yield estimates actual values quoted by respondents were used. Pure stands of perennial ryegrass had DM yield estimates ranging from 14.8 to 13.5 to 12.3 t DM ha^{-1} a^{-1} for the first, second and third years, respectively. Perennial ryegrass-clover had yields ranging from 13.5 to 11.8 to 11.0 t DM ha^{-1} a^{-1} for the first, second and third years, respectively (Table 2.1). While these data reflect a downward production trend in post-establishment seasons, this decline is not as pronounced as may be expected from reports by farmers of a production decline in year two. Possible reasons for this may be that: 1) very few farmers actually measure DM yield, therefore, much of these data (Table 2.1) are 'guessed' at by the farmers; 2) the sample size (i.e. those answering the yield related questions) declined from year one to three, presumably as farmers became more unsure of their estimates; and 3) it is suspected that only the more observant (and hence 'better') farmers attempted these questions.

Three methods of pasture utilization (defoliation) were identified, namely grazing, cutting or both. The majority of farmers (76 and 64% planting this species as a pure and clover-based stand, respectively) utilize grazing only (Figure 2.12). Fourteen and 34% of farmers (planting pure and clover-based stands, respectively) adopted a utilization programme incorporating 75% grazing and 25% cutting (i.e. for hay or silage). A further 2% of farmers planting perennial ryegrass-clover cut up to 50% of their pasture. Whether introducing a cutting programme into pasture utilization for perennial ryegrass helps enhance persistency will be examined later (see section 2.6.5).

Table 2.1 Estimated DM yield of perennial ryegrass (as pure and clover-based stands) for the first, second and third years

Year	Perennial ryegrass yield (t DM ha^{-1} a^{-1})			Perennial ryegrass/clover yield (t DM ha^{-1} a^{-1})		
	Average	Median	Range	Average	Median	Range
1	14.8±0.6 (20)[a]	15	8	13.5±0.3 (45)	13	9
2	13.5±0.1 (15)	14	14	11.8±0.5 (40)	12	14
3	12.3±1.1 (13)	12	14	11.0±0.5 (33)	12	10

[a] Sample size indicated in parenthesis

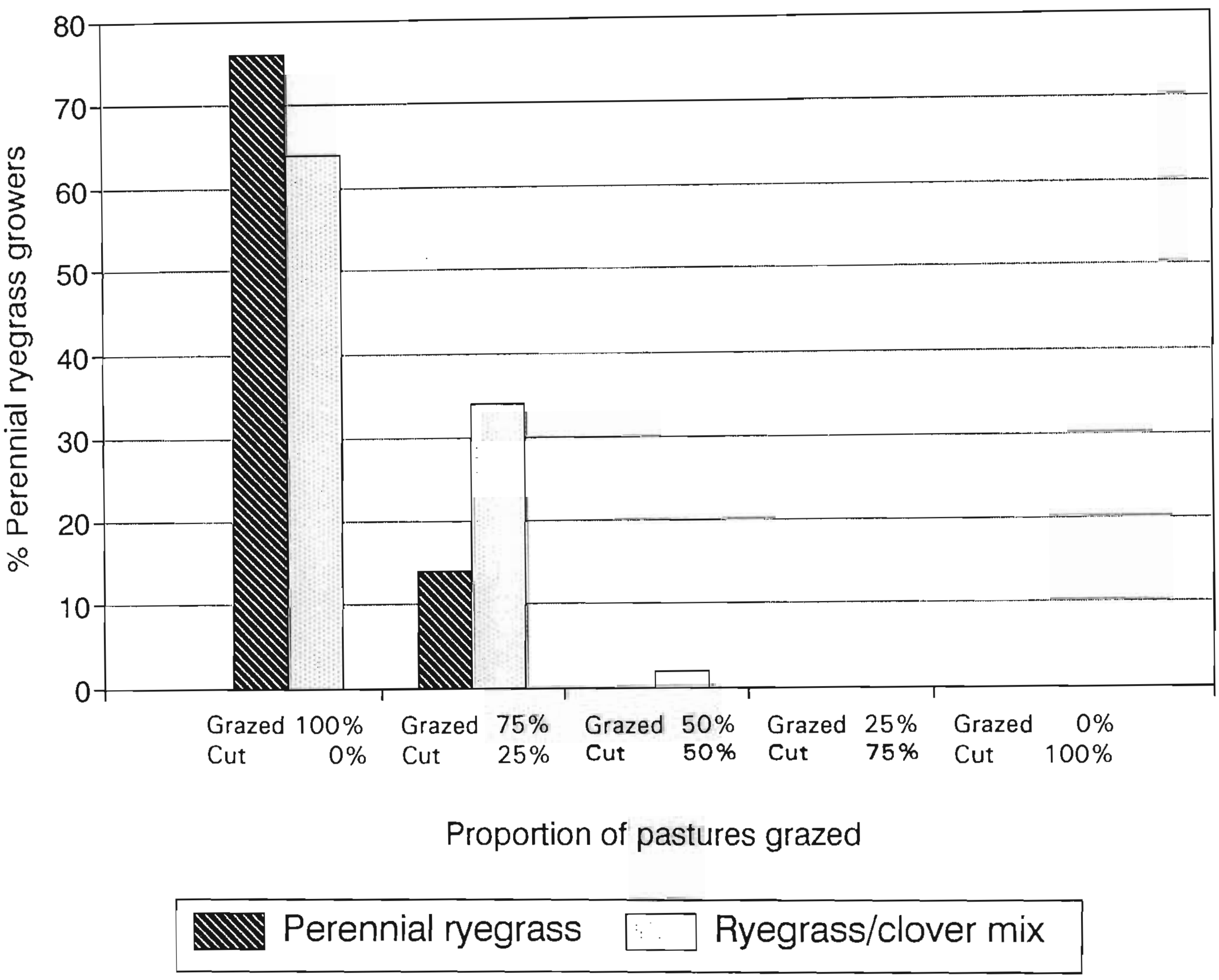


Figure 2.12 The proportion of perennial ryegrass farmers in KwaZulu-Natal, planting pure or clover-based stands, who incorporate cutting as part of their pasture utilization programme.

2.6.5 Identifying reasons affecting pasture survival

The major objectives of the correlation and regression analysis were: 1) to establish what influence various management variables have on the life-span of perennial ryegrass (as pure or clover-based stands) (correlation analysis); and 2) to identify which management variables are the most important in influencing pasture survival (stepwise multiple linear regression analysis).

For the purpose of these analyses it must be mentioned that the terms pasture 'persistence', 'survival', 'longevity' and 'life-span' are all taken to imply a measure of the number (unspecified) of years before re-establishment is necessary. Furthermore, it was assumed that farmers renovate or re-establish following equivalent levels of pasture degradation (e.g. weed invasion and decline in yield). This assumption was necessary because no objective measure of when a pasture requires re-establishment could be made from the survey.

It is stressed that production of a prescriptive empirical model was not the objective of this study. Such a predictive model will not be of practical use to farmers because of its lack of reliability. In addition, the reliability of such models in practical biological systems is also questionable (France & Thornley 1984; Edwards & Hamson 1989). It is believed that establishing trends and isolating the most important management variables (in terms of enhancing pasture longevity) will be beneficial, in practical terms, and afford perennial ryegrass farmers the opportunity to more successfully adapt their management to promote pasture longevity. For the purpose of these analyses, midpoints of the class intervals used in the questionnaire were used for the variables: rates of N (except for the upper-most level where actual values quoted by respondents were used); grazing intensity (where the lower range was taken as 2.5 cm, the mid range as 7.5 cm and the upper range as 12.5 cm); and irrigation (where levels ranged from 17.5 to 27.5 mm week^{-1}).

The correlation table for the dependent variable, pasture survival (years), and independent management variables (Table 2.2), revealed both positive and negative trends. Before discussing these results in any detail, it should be noted that correlation analysis does not necessarily imply that any management variable has a direct causal effect on pasture survival. The value of such an analysis lies more in its hypothesis generating ability and in highlighting possible trends or relations. Furthermore, the low correlation coefficients (r) established from this analysis (Table 2.2) indicates that very little of the variation in the data is accounted for by these (Steel & Torrie 1981). It is therefore stressed, that while some of these data may be statistically significant ($P \leq 0.05$ and $P \leq 0.01$) (Table 2.2), their biological significance should be interpreted with caution.

In terms of fertility management, reducing soil acidity and applying P and K to optimum recommended levels have a positive (but non-significant, $P>0.05$) influence on pasture survival (Table 2.2). In contrast, the rate of N application and the number of split applications of N are positively correlated with pasture survival for pure stands of perennial ryegrass ($r = 0.79$ and 0.83, respectively; $P \leq 0.01$), and to a lesser extent for perennial ryegrass-clover ($r = 0.41$ and 0.50, respectively; $P \leq 0.01$) (Table 2.2). These trends would suggest that high levels of N are necessary for promoting pasture longevity, particularly for pure stands of perennial ryegrass. Of perhaps even greater importance, however, is that applied N is evenly distributed over the year, particularly for pure stands of perennial ryegrass, and to a lesser extent for perennial ryegrass-clover. This observation is suggested by the highly significant ($P \leq 0.01$) positive correlation between pasture survival and the number of split applications of N.

Table 2.2 Correlation table for pasture survival (years to re-establishment) and management variables for perennial ryegrass pastures in KwaZulu-Natal (as pure and clover-based stands)

Variables	Correlation coefficient with: time (years) to pasture re-establishment	
	grass	grass/clover
Fertility management:		
reducing acidity (yes/no)	0.233	0.002
applying P (yes/no)	0.078	0.061
applying K (yes/no)	0.057	0.080
rates N (kg N ha^{-1} a^{-1})	0.786***	0.407***
split levels N (number)	0.835***	0.502***
Number of observations	25	60
Grazing management:		
time in (days) (summer)	-0.318**	-0.187
time in (days) (winter)	-0.394**	-0.166
time in (days) (spring/autumn)	-0.319	-0.184
time out (days) (summer)	0.538***	0.417***
time out (days) (winter)	0.533***	0.313
time out (days) (spring/autumn)	0.514	0.360**
intensity (cm) (summer)	0.213	0.366
intensity (cm) (winter)	-0.161	-0.302
intensity (cm) (spring/autumn)	-0.191	-0.338
utilization (increased cutting)	0.293	0.207
Number of observations	25	60
Irrigation management:		
level (mm $week^{-1}$) (summer)	0.265**	0.392
level (mm $week^{-1}$) (winter)	0.211	0.327
level (mm $week^{-1}$) (spring/autumn)	0.252	0.432***
Number of observations	25	60

** Significant at the 0.05 level of confidence
*** Significant at the 0.01 level of confidence

An inspection of the correlation coefficients for grazing variables illustrates that both negative and positive trends can be exerted on pasture survival. The length of the time spent in a pasture (time in) by grazing animals in a rotational grazing system negatively influences pasture survival for perennial ryegrass, both as pure (significantly, $P \leq 0.01$) and clover-based (non significantly, $P > 0.05$) stands (Table 2.2). Of these relations, the length of time in the pasture during summer (r = -0.318) and during winter (r = -0.394) were identified by the analysis as significant ($P \leq 0.01$ and $P \leq 0.05$, respectively) for pure stands of perennial ryegrass. While these relations were less pronounced for perennial ryegrass-clover, the results nonetheless suggest that under the sub-tropical conditions of KwaZulu-Natal, the period of occupation by grazing animals should be kept to a minimum in both pure perennial ryegrass and perennial ryegrass-clover pastures.

In considering the effect that period of absence (time out) from the pasture has on pasture survival, it is interesting to note the positive trends for perennial ryegrass, as pure and clover-based stands. Of these relations, period of absence from the pasture during summer (r = 0.54) and winter (r = 0.53) were both highly significant ($P \leq 0.01$) for pure stands of perennial ryegrass. For perennial ryegrass-clover, the period of absence during summer (r = 0.42; $P \leq 0.01$) and spring/autumn (r = 0.36; $P \leq 0.05$) were significant (Table 2.2).

Decreased grazing intensity during summer was positively, but non-significantly ($P > 0.05$), correlated with pasture survival, while during winter and spring/autumn, it was negatively (but again non-significantly, $P > 0.05$) correlated (Table 2.2).

Concerning pasture utilization (i.e. grazing or cutting), it was evident that reducing grazing and increasing cutting as a means of pasture utilization was positively correlated with survival of pure perennial ryegrass ($r = 0.293$) and clover-based stands ($r = 0.207$) (Table 2.2). These correlations, however, were non-significant ($P>0.05$).

Irrigation management was positively correlated with pasture survival for perennial ryegrass (as pure and clover-based stands) (Table 2.2). For pure stands of perennial ryegrass, summer irrigation was highlighted as a significant relation ($r = 0.27$; $P\leq0.05$), while for perennial ryegrass-clover, irrigation during spring/autumn ($r = 0.43$) was significant ($P\leq0.01$). These results stress the importance of irrigation during summer as a management variable affecting pasture longevity for pure stands of perennial ryegrass. On the other hand, irrigation management during spring/autumn may be an important variable affecting the longevity of the perennial ryegrass-clover pasture.

After identifying the trends (positive or negative) of management variables on pasture survival, a stepwise multiple linear regression analysis was used to identify the most important of these (Table 2.3). Regression analyses were conducted, independently, on fertility management variables, grazing management variables and irrigation management variables. The reason for this approach was that, in practical terms, such management variables are applied independently of one another. For example, grazing management decisions on intensive pastures are made independently of fertilizer considerations on the same pasture. Presumably, these independent decisions will also be geared towards maximising production, quality and longevity of the pasture.

Table 2.3 illustrates the relation between pasture survival (years) and management variables for perennial ryegrass (as pure and clover-based stands). Only those variables identified by the analysis as being the most influential on pasture survival (i.e. those entering the regression equation) are presented. These

Table 2.3 Regression estimates for pasture survival (years to re-establishment) and management variables for perennial ryegrass pastures in KwaZulu-Natal (as pure and clover-based stands)

Variables[a]	Regression coefficients[b] time (years) to pasture re-establishment	
	grass	grass/clover
Fertility management:		
Constant	0.3178	1.9807
split levels N (number)	0.5302(12.682)***	0.3388(5.046)***
R^2	0.6924	0.2633
'F' value	160.8328***	13.6901***
Number of observations	25	60
Grazing management:		
Constant	0.0608	3.5527
time in (days) (summer)	-0.5688(-3.264)***	-----
time in (days) (winter)	-0.4487(-2.188)**	-----
time in (days)(spr/atmn)	-----	-----
time out (days) (summer)	3.8971(8.036)***	2.8917(3.970)***
time out (days) (winter)	-----	-----
time out (days) (spr/atmn)	-----	0.8571(1.917)*
R^2	0.6990	0.5104
'F' value	28.4833***	10.2506***
Number of observations	25	60
Irrigation management:		
Constant	3.5747	0.7691
(mm week^{-1}) (summer)	0.1147(2.303)**	-----
(mm week^{-1}) (spr/atmn)	-----	0.1427(4.006)***
R^2	0.0572	0.1749
'F' significance	5.3050**	16.05010***
Number of observations	25	60

a Only variables entering stepwise regression equation indicated
b Numbers in parenthesis are 't' ratios
* Significant at the 0.10 level of confidence
** Significant at the 0.05 level of confidence
*** Significant at the 0.01 level of confidence

were variables that were significant at levels below $P \leq 0.10$. With reference to Table 2.3, the equations were significant at the 0.01 or 0.05 levels of significance, with 'F' values ranging from 5.31 to 160.83. The regression coefficients of all the variables in the equation had 't' values showing that they (the coefficients) were significant at levels ranging from 0.01 to 0.10.

The coefficient of determination adjusted for degrees of freedom, R^2, indicated that for fertility management variables, 69% (pure stands) and 26% (perennial ryegrass-clover) of the total variation in pasture survival (years) was explained by the number of split levels of N (Table 2.3). Although the level of variation explanation by R^2 is low for perennial ryegrass-clover, the high 't' ratios and significant 'F' ratios do establish the existence of a meaningful relation.

The R^2 for grazing management variables for pure stands of perennial ryegrass accounted for 70% of the variation in pasture survival (years). Of these variables, period of occupation of the pasture by grazing animals during summer ($P \leq 0.01$) and winter ($P \leq 0.05$), and period of absence from the pasture during summer ($P \leq 0.01$) were identified as influential (Table 2.3). For perennial ryegrass-clover, the regression accounted for 51% of the variation in pasture survival, where time out of the pasture during summer ($P \leq 0.01$) and spring/autumn ($P \leq 0.10$) were identified as important variables.

For irrigation management variables, the regression accounted for 6 to 17% of the variation for perennial ryegrass (pure and clover-based stands, respectively) (Table 2.3). While the coefficient of determination was low, significant 't' and 'F' ratios established that the relation between pasture survival and irrigation levels during summer ($P \leq 0.01$) (for pure stands of perennial ryegrass) and during spring/autumn ($P \leq 0.01$) (for perennial ryegrass-clover) was statistically meaningful.

The implications of the regression analyses, in terms of pasture survival, are discussed below.

(a) Fertility management

While application rates of N were highly correlated with pasture survival for pure stands of perennial ryegrass and to a lesser extent for perennial ryegrass-clover (Table 2.2), these were excluded in the regression analysis. Interestingly, the number of split applications of N to pure stands of perennial ryegrass was identified as the most important fertility management variable ($P \leq 0.01$). This was also the case for perennial ryegrass-clover ($P \leq 0.01$), although the relation was not as strong as that for pure stands of perennial ryegrass (Table 2.3).

These results suggest that while high rates of N application (i.e. $\geq$ 350 and $\geq$ 250 kg N ha^{-1} a^{-1} to pure stands of perennial ryegrass and clover-based stands, respectively) may be important for pasture survival, an even distribution of the applied N (i.e. having many split applications) is even more important to pasture survival. In practical terms, therefore, perennial ryegrass farmers could improve pasture survival by applying N evenly over the entire year (excluding perhaps periods of slow pasture regrowth during winter). Addressing such a management option should, however, be based on the assumption that soil acidity, P and K levels are ameliorated to recommended levels.

(b) Grazing management

In terms of grazing management for pure stands of perennial ryegrass, a short period of occupation by grazing animals was identified as having an important effect on enhancing pasture survival during summer and to a lesser extent during winter (Table 2.3). Long periods of occupation by grazing animals have a negative influence on pasture survival. This is perhaps accentuated by the fact that animals exert trampling, selection and excretion effects upon the sward. In addition, animals tend to graze regrowth, a condition which becomes more pronounced the longer animals remain on a pasture. Such influences could be minimized by reducing the period of occupation of grazing animals (e.g. by strip grazing or by having more camps). In effect, however, the period of absence of animals from the pasture during summer was identified as the most important grazing variable addressing pasture survival. A practical implication of these results is that perennial ryegrass requires adequate periods of recovery after grazing during summer (e.g. $\geq$ 21 days; CHAPTER 3).

For perennial ryegrass-clover, the period of absence from the pasture during summer, and to a lesser extent during spring/autumn, is also strongly related to pasture survival (Table 2.3). Although the regression analysis did not establish the period of occupation (during any season) as a meaningful explanation for pasture survival, pasture recovery (i.e. absence after grazing) during summer, as for pure stands of perennial ryegrass, was extremely important.

It was noted that grazing intensity was not highlighted by the regression analysis as an important contributor to pasture survival. Researchers constantly stress the importance of grazing intensity as a management option for pastures (Tainton 1974; Grant *et al*. 1981; Korte *et al*. 1982; Lowe & Bowdler 1988). Local literature (Goodenough *et al*. 1991) advises lenient grazing of perennial ryegrass (e.g. 8 to 10 cm) during summer (presumably to keep the sward base cool) and more intense defoliation during spring/autumn and winter (to promote tillering). This study suggests that periods of occupation and absence by grazing animals from the pasture are more important considerations for perennial ryegrass pasture survival under the sub-tropical conditions of KwaZulu-Natal than grazing intensity.

(c) Irrigation management

The correlation analysis illustrated that a positive relation exists between increasing the level of water application and pasture survival in all seasons for perennial ryegrass (as pure and clover-based stands) (Table 2.2). For pure stands of perennial ryegrass, the regression analysis identified summer irrigation ($P \leq 0.05$) as an important variable contributing to pasture survival (Table 2.3). While the importance of irrigating temperate perennial grass species under the sub-tropical conditions of KwaZulu-Natal is fairly well understood (Goodenough *et al.* 1991), it should be noted that this result is most likely due to four of the respondents not applying any irrigation whatsoever during summer. Unfortunately, the summer rainfall for KwaZulu-Natal is not reliable enough to exclude the need for irrigation during this season. These four respondents re-establish their pastures every three years.

For perennial ryegrass with clover, irrigation during spring/autumn was identified as an important factor influencing pasture survival (Table 2.3). Again, four of the respondents indicated that they do not irrigate during summer and spring/autumn, relying on natural rainfall during these seasons. Interestingly, three of these four respondents had pastures which survived for less than four years.

2.6.6 Summary of management variables and their respective influence on pasture survival

In order to summarize the effects of management variables on pasture longevity, the results from all surveyed respondents were categorized into relatively more 'successful' and 'unsuccessful' groups. This was conducted separately for perennial ryegrass farmers planting this species as a pure stand (Table 2.4) or in association with clover (Table 2.5). The results depicted in Figure 11 (see section 2.6.4) were used to define the 'successful' versus 'unsuccessful' group. Since the majority (27%) of farmers planting pure stands of perennial ryegrass re-establish their pastures after three years (Figure 2.11), the defining limit for the 'successful' group was selected as those whose pastures persisted for four years or longer. This 'cut-off' point gave a maximum sample size of 13 for pastures persisting for less than four years, and 12 for pastures persisting for four years and longer.

For those farmers planting perennial ryegrass with clover, the majority (31%) were observed to re-establish their pastures after four years (Figure 11). Therefore, the 'successful' group was defined as those whose pastures persisted for five years or longer. This 'cut-off' point gave a maximum sample size of 34 for pastures persisting for less than five years, and 26 for pastures persisting for five years and longer.

These summarized results (Tables 2.4 & 2.5) support the results of the correlation and regression analyses (Tables 2.2 & 2.3). Evident from the summary, in terms of fertility management, is that higher rates of N application and more split dressings of N are associated with the 'successful' groups (both pure and clover-based stands, respectively). For pure stands of perennial ryegrass, the 'unsuccessful' group applied, on average, 294 kg N ha^{-1} a^{-1} in 4.9 split applications, as opposed to the 'successful' group applying 367 kg N ha^{-1} a^{-1} in 6.8 split applications (Table 2.4). This trend was not as marked for perennial ryegrass with clover, where the 'unsuccessful' group applied an average of 234 kg N ha^{-1} a^{-1} in 4.2 split applications, as opposed to the 'successful' group applying 258 kg N ha^{-1} a^{-1} in 5.0 split applications (Table 2.5).

As far as grazing management was concerned, the period of occupation (days in) of the pasture by grazing animals was markedly different between the 'unsuccessful' and 'successful'

Table 2.4 Summary of management variables for pure perennial ryegrass pastures lasting less than four years versus those lasting four years or longer, in KwaZulu-Natal

Variables	Pastures < 4 years				Pastures ≥ 4 years			
	sample size	mean	median	range	sample size	mean	median	range
Fertility management:								
rates N (kg N ha^{-1} a^{-1})	13	294±34.0	350	350	12	367±54.8	350	750
split levels N (number)	13	4.9±0.7	4	10	12	6.8±0.9	6.5	10
Grazing management:								
time in (days)(summer)	10	5.8±1.3	6	13	9	3±0.6	3	6
time in (days)(winter)	10	4.9±1.0	6	9	9	3.2±0.7	3	6
time in (days)(spring/autumn)	10	6.1±1.4	6	13	9	3.1±0.6	3	6
time out (days)(summer)	10	16.6±2.4	16	21	10	21.9±2.0	21	17
time out (days)(winter)	10	27.9±5.5	26	53	10	28.3±2.3	26.5	24
time out (days)(spring/autumn)	10	18.6±2.4	17	28	10	18.6±1.1	21	9
intensity (cm)(summer)	11	6.1±0.9	7.5	10	12	7.5±0.8	7.5	10
intensity (cm)(winter)	11	5.7±1.0	7.5	10	12	5±0.8	5	5
intensity (cm)(spring/autumn)	11	7.0±0.8	7.5	10	12	5.8±0.9	7.5	10
Irrigation management:								
level (mm $week^{-1}$)(summer)	13	13.1±3.0	17.5	22.5	10	21.5±1.0	22.5	10
level (mm $week^{-1}$)(winter)	13	18.0±0.9	17.5	10	10	18.5±0.7	17.5	5
level(mm $week^{-1}$) (spring/autumn)	13	17.5±2.2	22.5	22.5	10	19.3±2.4	22.5	27.5

Table 2.5 Summary of management variables for perennial ryegrass clover-based pastures lasting less than five years versus those lasting five years or longer, in KwaZulu-Natal

Variables	Pastures < 5 years sample size	mean	median	range	Pastures ≥ 5 years sample size	mean	median	range
Fertility management:								
rates N (kg N ha^{-1} a^{-1})	34	234±21.5	250	550	26	258±26.1	250	575
split levels N (number)	34	4.2±0.5	5	13	26	5±0.6	5	9
Grazing management:								
time in (days)(summer)	27	5.0±1.1	3	25	20	2.7±0.4	2	6
time in (days)(winter)	28	5.7±1.3	3	31	20	2.7±0.4	2	6
time in (days)(spring/autumn)	27	5.3±1.2	4	25	20	3.1±0.6	2	10
time out (days)(summer)	28	16.6±1.0	17.5	28	20	21.4±1.2	21	17
time out (days)(winter)	29	27.6±2.2	30	53	20	29.3±3.1	25	46
time out (days)(spring/autumn)	28	17.9±1.0	17	23	20	18.1±1.6	18.5	28
intensity (cm)(summer)	33	8.1±0.6	7.5	10	25	9.1±0.6	7.5	10
intensity (cm)(winter)	32	6.7±0.6	7.5	10	25	6.3±0.7	7.5	10
intensity (cm)(spring/autumn)	33	8.0±0.5	7.5	10	25	7.9±0.7	7.5	10
Irrigation management:								
level (mm $week^{-1}$)(summer)	34	19.6±1.3	22.5	27.5	26	22.3±0.7	22.5	10
level (mm $week^{-1}$)(winter)	34	19.1±0.5	17.5	10	26	19.6±0.6	17.5	10
level (mm $week^{-1}$) (spring/autumn)	34	20.0±0.6	22.5	10	26	22.1±0.6	22.5	10

groups during all seasons and for pure and clover-based pastures (Tables 2.4 & 2.5). For both pasture types (pure and clover-based stands), the 'unsuccessful' group had a period of occupation ranging from 4.9 to 6.1 days as opposed to an occupation period ranging between 3.0 to 3.2 days for the 'successful' group. In terms of time out of the pasture, the most marked difference between the two groups occurred during summer (rather than winter and spring/autumn), both pure and clover-based pastures (Tables 2.4 & 2.5). This difference was about five days in favour of the 'successful' group. Interestingly, there were no really marked differences in the respective grazing intensity levels between the relative 'success' groups for the two pasture types (pure and clover-based stands) for any season (Tables 2.4 & 2.5).

In considering irrigation management, apart from the marked difference between the two groups of about 8 mm week^{-1} during summer for pure stands of perennial ryegrass (Table 2.4), the differences were only slight for all other seasons. A possible reason for the difference in summer irrigation was, as mentioned previously (section 2.6.5), that four of the respondents did not irrigate their pastures during summer. For perennial ryegrass-clover, the differences in irrigation between the relative 'success' groups were negligible in all seasons (Table 2.5).

2.6.7 General comments made by the farmers

This section evaluates comments made by the respondents. It comprises sub-sections which include: the advantages and disadvantages of perennial ryegrass relative to annual ryegrass; the possibility of using clover as a base pasture and repeatedly over-sowing perennial ryegrass into it; and the possibility of over-sowing perennial ryegrass each autumn with oats. Within each of these sub-sections, the most common responses elicited are noted as a percentage of the total number of questionnaires used (72), followed by a brief discussion.

2.6.7.1 Advantages of perennial ryegrass

The advantages of perennial ryegrass, relative to annual ryegrass, are presented (Table 2.6). These results indicate that the most popular advantages of perennial ryegrass over annual ryegrass, as perceived by farmers, are the greater summer production (55%) and the lower costs associated with not having to re-establish the pasture annually (47%). Traditionally, annual ryegrass in South Africa is established in autumn (D.C.W. Goodenough 1994, personal communication, Roodeplaat Grassland Institute, Private Bag X9059, Pietermaritzburg, 3 200, South Africa). These pastures then provide quality forage for intensive livestock systems during late autumn, winter and spring, following which they flower and are ploughed in. Therefore, they do not usually contribute to the summer fodder flow (unless they are spring planted), as does perennial ryegrass.

The current estimated costs of establishing and maintaining annual ryegrass with clover for its full productive season is R3 346.99 ha^{-1} (including seed, lime, fertilizers, irrigation, labour, machinery costs and interest on operating capital) (Combud 1994). Assuming a yield of 12 t DM ha^{-1}, this costs R278.92 t^{-1} DM to produce (Combud 1994). Perennial ryegrass with clover on the other hand, costs R4 469.24 ha^{-1} to establish and maintain for a full productive year (Combud 1994). At an estimated annual DM yield of 13 t DM ha^{-1}, this costs R343.79 t^{-1} DM. While this is higher than for annual ryegrass, the total cost to maintain perennial ryegrass for its second and subsequent years is estimated at R2 238.79 ha^{-1} a^{-1} (Combud 1994). If 12 t DM ha^{-1} is produced in the second year, this would cost R186.57 t^{-1} DM. Therefore, maintaining perennial ryegrass (with clover) for two years, at current estimated costs (estimated at R6 708.03), will amount to almost the same as establishing annual

Table 2.6 The advantages of perennial ryegrass over annual ryegrass as perceived by farmers (responses are noted as a percentage of 72 questionnaires used)

Percentage (%)	Response
55	Perennial ryegrass produces during the summer and early autumn periods when annual ryegrass does not
47	Reduction in costs due to not having to re-establish perennial ryegrass annually, as is necessary with annual ryegrass
8	Production and quality of perennial ryegrass is high, and a better DM intake is achieved than with annual ryegrass
6	The cost of forage per tonne of DM produced with perennial ryegrass is lower than with annual ryegrass
6	A perennial ryegrass pasture helps overcome the negative effects of summer ploughing, and therefore has a lower erosion potential than annual ryegrass
3	Perennial ryegrass helps build up soil organic matter (OM) levels since cultivation is not practised annually
3	Perennial ryegrass is conducive to better land utilization over 12 months of the year than annual ryegrass

ryegrass for two years (estimated at R6 693.98). Thereafter (i.e. third and subsequent years), the costing will favour perennial ryegrass. A cost analysis conducted by Eckard (1994) also highlighted the point that a perennial ryegrass-clover pasture lasting three years will be more economical than re-establishing annual ryegrass annually for three years. It is surprising, therefore, that only 6% of the respondents (Table 2.6) recognised this as an advantage to growing perennial ryegrass, relative to annual ryegrass.

Eight per cent of the respondents (Table 2.6) cited the high quality and good DM intake of perennial ryegrass by livestock as an advantage of perennial ryegrass. The *in vitro* digestibility of perennial ryegrass under temperate conditions is in the range or 65 to 80% (Morton *et al.* 1992; Barker *et al.* 1993; Stevens & Turner 1993), while crude protein (CP) values for well managed perennial ryegrass pastures range from 18 to 26% on a DM basis (Baker & Leaver 1986). While the quality of perennial ryegrass is high, it is generally believed that the quality of annual ryegrass is even higher (e.g. Bredon & Stewart 1978). However, the DM content of perennial ryegrass is higher than that of annual ryegrass (Bredon & Stewart 1978) and this will facilitate better DM intake of perennial ryegrass by the grazing animals (McDonald *et al.* 1988).

The potential negative effects of summer ploughing (viz. erosion) is cited as an advantage of growing perennial ryegrass by 6% of the respondents (Table 2.6). This point is closely linked to the fact that soil OM build-up is promoted by not having to cultivate the area annually (3% of the respondents). In addition, perennial ryegrass utilizes the area effectively for 12 months of the year (3% of respondents) as opposed to autumn planted annual ryegrass which only utilizes an area for eight months of the year and the area will remain unproductive for four months. Considering that intensive pastures require high potential soils, and together with the continual breakdown of soil structure and OM due to annual cultivation (Hefer 1994), annual ryegrass could be considered to use the land resource inefficiently. In this respect therefore, these arguments do indeed place perennial ryegrass above annual ryegrass as a choice of a species for intensive pastures.

2.6.7.2 Disadvantages of perennial ryegrass

The disadvantages of perennial ryegrass relative to annual ryegrass are presented (Table 2.7). Relative to annual ryegrass, many farmers (35%) in this study consider the lower yields of perennial ryegrass during winter to be a disadvantage. This observation has been documented previously for South African conditions (Eckard 1994).

The decrease in production over time (27%) and the observation that weeds tend to invade the pasture during its second year after establishment (24%) (Table 2.7) do constitute major problems for perennial ryegrass growers. It is believed, however, that by addressing the management issues highlighted in other sections of this study (including those from CHAPTER 3), such as longer rest periods during summer, such problems will be minimized.

Thirteen per cent of respondents (Table 2.7) acknowledged that the overall management of perennial ryegrass is more difficult than that of annual ryegrass. Mismanagement of annual ryegrass will not, of course, affect this pasture during the following year so that management errors are, in effect, buried when the pasture is re-planted the following year. However, any form of mismanagement of perennial ryegrass may potentially influence its survival in subsequent years, and so attention must be paid its careful management.

Farmers stated that irrigation costs associated with perennial

Table 2.7 The disadvantages of perennial ryegrass relative to annual ryegrass as perceived by farmers (responses are noted as a percentage of 72 questionnaires used

Percentage (%)	Response
35	There is a tendency for perennial ryegrass to produce lower DM yields during winter than annual ryegrass
27	The DM production of perennial ryegrass decreases with time, particularly after the establishment year
24	Perennial ryegrass is subject to weed invasion during the second and subsequent years after establishment
13	Management of perennial ryegrass is more difficult than that of annual ryegrass
11	Irrigation costs for perennial ryegrass are higher than those of annual ryegrass
6	Perennial ryegrass production declines due to soil compaction occurring over time
4	Fertilizer requirements for perennial ryegrass are higher than those of annual ryegrass
3	The cost of perennial ryegrass seed is higher than that of annual ryegrass

ryegrass are higher than those for annual ryegrass (11%) (Table 2.7). This stems primarily from the fact that perennial ryegrass requires irrigation year-round, whereas annual ryegrass requires irrigation for only about eight months of the year. Total estimated irrigation costs over a whole production year for perennial ryegrass are R884.80, while those for annual ryegrass for its full productive period are R654.18 (Combud 1994).

The production of perennial ryegrass is reported to decline as a result of soil compaction (6%) (Table 2.7). This condition is believed to arise where irrigation and a period of occupation by grazing animals coincide. The hoof action of the animal on the moistened soil surface leads to compaction and subsequent reduction in DM yield (Edmond 1963; 1964; Curll & Wilkins 1983). Such conditions will not have time to manifest themselves in annually re-established systems. This issue, however, has received no research attention in perennial ryegrass pastures in South Africa. Perhaps compaction is an issue related to the negative effects of long periods of occupation (i.e. $\geq$ 7 days) which was highlighted as a variable influencing pasture survival (section 2.6.5 & 2.6.6). This may occur because, invariably with long periods of occupation, grazing and irrigation are more likely to coincide than where periods of occupation are much shorter.

Four per cent of respondents (Table 2.7) cited higher fertilizer costs for perennial ryegrass than for annual ryegrass. Since many of these pastures are legume based, the lime requirements for perennial ryegrass or annual ryegrass with clover are identical because the soil acid saturation levels are set by the clover (i.e. < 1%) (Manson *et al.* 1990). However, if perennial ryegrass is established as a pure stand, its lime requirements are higher than those of a pure stand of annual ryegrass, since the current recommended soil acid saturation levels for perennial and annual ryegrass are 10 and 25%, respectively (Manson *et al.*

1990). Current recommendations for soil P and K levels are 25 and 140 mg L^{-1}, respectively, for both perennial and annual ryegrass (Manson *et al.* 1990). As far as recommended N application levels are concerned, these are also similar at 350 kg N ha^{-1} a^{-1} (Manson *et al* 1990). However, up to 450 kg N ha^{-1} a^{-1} has also be advocated for pure stands of perennial ryegrass (Eckard 1994). For perennial ryegrass with clover, 250 kg N ha^{-1} a^{-1} is recommended, while 350 kg N ha^{-1} a^{-1} is still advocated for high yielding annual ryegrass with clover (Manson *et al* 1990). Citing higher fertility costs for perennial ryegrass than for annual ryegrass, given the current literature recommendations for local conditions, therefore seems questionable.

Three per cent of respondents mentioned that perennial ryegrass seed is more expensive than that of annual ryegrass (Table 2.7). All perennial ryegrass seed is currently imported and is sold at about R10 kg^{-1} for the cheapest perennial ryegrass cultivar. Some annual cultivars are locally produced and the cheapest of these on the market is about R3.50 kg^{-1} (McDonalds Seeds, P.O. Box 238, Pietermaritzburg, 3200, South Africa). Thus, at recommended seeding rates of 25 kg ha^{-1}, the cheapest seed costs for perennial ryegrass will be R250 ha^{-1}, while for annual ryegrass it will be R87.50 ha^{-1}. While some may consider this to be a large difference (R162.50 ha^{-1}), seed is a small component of the total cost involved, and at current estimated total pasture costs, maintaining perennial ryegrass for three years or longer will more than offset this difference.

2.6.7.3 Over-sowing perennial ryegrass into a clover pasture

The majority of respondents were not in favour of this idea; 46% answered no to this option while 34% answered yes. Arguments against this possibility included:

1) it is a difficult option to manage, and clover is too much

of a bloat risk to consider establishing on its own;
2) the yield from clover on its own is too low;
3) perennial ryegrass seed is too expensive to use in annual over-sowing;
4) clover has the tendency to out-compete perennial ryegrass seedlings; and
5) too much attention must be paid to reducing soil acidity to consider planting clover.

Although 34% of respondents answered yes to this option, no specific arguments were given in its favour.

2.6.7.4 Over-sowing oats into perennial ryegrass

This option was also generally not accepted; 59% of respondents were against this idea while only 14% were in favour. Arguments against over-sowing oats into perennial ryegrass included:
1) oats cannot tolerate the same intense level of defoliation as perennial ryegrass and dies out;
2) oats swamps out perennial ryegrass during autumn and spring; and
3) this system tends to shorten the life of perennial ryegrass.

While 14% of respondents answered yes to this option, no actual arguments were offered in favour of it.

2.7 Summary and conclusions

The objective of this study was to characterise the current management practices applied to perennial ryegrass in KwaZulu-Natal. In the absence of quantitative research, this was viewed as an opportunity to gain insight into the current management practices applied to perennial ryegrass under sub-tropical conditions. More specifically, the study was designed to establish possible reasons for the success, and conversely, the failure of perennial ryegrass systems under sub-tropical conditions in KwaZulu-Natal.

The study drew its information from a carefully constructed questionnaire which was targeted at all known perennial ryegrass growers in KwaZulu-Natal. From 150 questionnaires which were posted, a useable total of 72 emerged to form the base of this study, a 48% response, which is considered good for studies of this nature. Correlation and stepwise multiple linear regression analyses were conducted on the data to identify management variables influencing pasture survival.

Areas in KwaZulu-Natal that are currently the most popular for perennial ryegrass cultivation are those of Bioclimatic regions 3 (Mist Belt) and 4 (Highland Sourveld). Other areas in KwaZulu-Natal in which perennial ryegrass is used are Bioclimatic regions 5 (Montane), 6 (Upland (moist)), 7 (Riverine) and 8 (Upland (drier)), but to a limited extent.

The most popular season for establishing perennial ryegrass (as pure or clover-based stands) is autumn rather than spring, presumably to avoid weed infestation, which commonly occurs in spring-established pastures, and to avoid exposing young developing plants to extreme early summer temperatures.

Data from this study indicate that most perennial ryegrass growers in KwaZulu-Natal plant this species with clover. In addition, it appears that farmers are more confident in planting larger areas when this species is combined with clover. A very conservative estimate shows that 853 ha are currently under perennial ryegrass/clover pastures in KwaZulu-Natal, while 295 are under pure stands of perennial ryegrass.

The greatest use of perennial ryegrass, as pure or clover-based stands, is made by dairy farmers. This is followed by fat lamb and beef production enterprises. With an improvement in the knowledge on how to manage perennial ryegrass under sub-tropical conditions, it is believed that this species will gain in popularity for use in fat lamb and beef production systems.

It was observed that the majority of farmers utilize only grazing as a means of harvesting perennial ryegrass (pure and clover-based stands), while a small proportion defoliate their pastures by both cutting and grazing. Cutting as a means of pasture utilization was positively correlated with pasture longevity, although not significantly so.

Most growers of perennial ryegrass (pure and clover-based stands) implement pasture renovation (sod-seeding being the most popular option), and it is suggested that this may allow an additional year's production from the pasture before re-establishment is required. While most farmers report a production decline from perennial ryegrass pastures (pure and clover-based stands) over time, it is interesting to observe that the majority of those planting this species without clover renovate their pastures after two years. This is in contrast to those farmers planting perennial ryegrass with clover, where the majority implement pasture renovation only after three years. These results suggest that pastures containing clover have a better chance of survival than those without clover. This observation is also supported by data on the frequency of complete re-establishment. Of the farmers planting pure stands of perennial ryegrass, the highest proportion re-establish every three years. Compared with this, the greatest proportion of farmers planting perennial ryegrass-clover, re-establish their pastures only every four years.
Dry matter yield estimates made by farmers for the first, second and third year of a pure stand of perennial ryegrass were 14.8 to 13.5 to 12.3 t DM ha^{-1} a^{-1}, respectively. Yields of perennial ryegrass with clover were 13.5 to 11.8 to 11.0 t DM ha^{-1} a^{-1},

respectively. Although these downward trends are not as drastic as expected, farmers are generally in support of the idea of re-establishing their pastures biennially, provided the DM yield decline in year two is not too great.

From the data presented in this study, the following management implications are suggested to enhance pasture longevity.

(a) Fertility management

The results suggest that while high rates of N application (e.g. 350 and 250 kg N ha^{-1} a^{-1} to perennial ryegrass as pure and clover-based stands, respectively) may be important for pasture survival, a consistent distribution of the applied N is even more important. It is suggested that at least seven split applications of N onto pure stands of perennial ryegrass and five onto perennial ryegrass-clover are made. In practical terms, therefore, the less successful perennial ryegrass farmers can improve pasture survival by applying N evenly over the entire year (excluding perhaps periods of slow pasture regrowth during winter). Such a management option is likely to be successful only if soil acidity, P and K levels are ameliorated to recommended levels.

(b) Grazing management

In terms of grazing management for pure stands of perennial ryegrass, the length of the period of occupation has been identified as having an important effect on pasture survival. During the summer and to a lesser extent during winter, long periods of occupation (e.g. seven days) by grazing animals have a negative influence on pasture survival. Such an influence could be minimized by reducing the period of occupation of grazing animals (e.g. by strip grazing or increasing the number of camps). In addition, the period of absence of animals from the pasture during summer was identified as the most important grazing variable affecting pasture survival. Practical implications of these results are that perennial ryegrass requires adequate periods of recovery after grazing during summer (i.e. > 21 days). In addition, perennial ryegrass appears sensitive under sub-tropical conditions to long periods of occupation by grazing animals (i.e. > 3 days) during summer, and to a lesser extent during winter.

For perennial ryegrass-clover, the period of absence from the pasture during summer is also strongly related to pasture survival, as is, although to a lesser extent, that during spring/autumn. Although the analysis does not identify the period of occupation (during any season) as a meaningful explanation for pasture longevity, pasture recovery (i.e. period of absence from grazing) during summer, as in pure stands of perennial ryegrass, is extremely important.

It was noted that grazing intensity was not highlighted by the regression analysis as an important contributor to pasture survival. This study suggests that periods of occupation and absence by grazing animals from the pasture are more important considerations for the survival of perennial ryegrass pastures under the sub-tropical conditions of KwaZulu-Natal than is grazing intensity.

(c) Irrigation management

A positive relation exists between increasing the level of water applied and pasture survival in all seasons for perennial ryegrass (as pure and clover-based stands). For pure stands of perennial ryegrass, summer irrigation is an important variable contributing to pasture survival. For perennial ryegrass-clover, irrigation during spring/autumn is identified as an important factor influencing pasture survival.

This study has established what the current management practices of perennial ryegrass are under the sub-tropical conditions of

KwaZulu-Natal. Furthermore, by considering the management approaches of the relatively more successful farmers, it has highlighted some important management considerations that can be practically implemented by other farmers to help enhance the longevity of their pastures. Mechanisms that may control some of these responses will be covered in the following chapters.

CHAPTER 3

THE INFLUENCE OF GRAZING MANAGEMENT ON PERENNIAL RYEGRASS

3.1 Introduction

Data emerging from trials on adequately fertilized and irrigated pastures have shown the economic benefits of their use and resulted in a rapid increase in the use of intensive irrigated ryegrass for dairy, beef and sheep systems (Eckard 1994). While numerous cultivars of perennial ryegrass have been available for many years, their use in animal production systems in South Africa has, however, been limited because of their lack of persistence. This has also been found to be a problem under the sub-tropical conditions of Australia (Fulkerson *et al.* 1993). Even under temperate environments such as those encountered in New Zealand, much research is directed towards improving the persistence of temperate pasture species (Barker & Dymock 1993; Barker *et al.* 1993).

The main reason for non-persistence of perennial ryegrass is apparently the lack of knowledge on how to manage this species under sub-tropical conditions. Eckard (1994) reported a dearth of information regarding the grazing management and fertilizer requirements for perennial ryegrass under local conditions. Also raised by Eckard (1994) was the concern that private pasture consultants are offering farmers advice on the management of these pastures without locally applicable data on which to base their advice. Field trials, therefore, need to be designed to address the issues regarding management of perennial ryegrass using grazing under South African conditions.

With respect to physiology of herbage re-growth, much information available on the relation between rate of re-growth and the frequency and severity of defoliation of plants is derived from cutting trials (Binnie & Harrington 1972; Baker & Younger 1986; Davidson & Robson 1986; Evans & Williams 1987; Fulkerson & Michell 1987; Fulkerson *et al.* 1993; Fulkerson & Slack 1994). It is generally appreciated that severity of defoliation is not adequately described by height of cutting, especially in plants that modify their growth habit so that an increasing proportion of their photosynthetic tissue lies below the height of cut (Spedding 1965). On the other hand, grazing is one of the most important methods of pasture utilization, but because of the high requirements of land, labour, equipment and finance associated with animal trials, cutting trials tend to be widely used to evaluate various pasture management factors. Unfortunately, cutting trials cannot accommodate the effects of grazing which include treading, selection and excretion (Thom *et al.* 1986; Thom 1991). It is, therefore, important to design trials that will evaluate the effects of defoliation management under the conditions that will ultimately apply at the farm level, namely grazing.

It was the objective of this study to evaluate the persistence of perennial ryegrass under grazing. Persistence was monitored in terms of: tiller population demographies; relative DM yield contribution by the planted species to total production; quality of the total pasture; perennial ryegrass vigour; ingression of weed species; and root development of the grass.

3.2 Experimental procedure

This section describes the study site, the grazing treatments, the design and field lay-out of the trial. Specific experimental details such as sampling procedures and analyses pertaining to individual objectives that the study will address are described in the relevant sections.

3.2.1 Study area

The trial was conducted at the University of Natal's research farm, Ukulinga, 6 km south east of Pietermaritzburg (29°24'E, 30°24'S; altitude 700 m; mean annual precipitation 705 mm from October to February). Mean monthly maximum and minimum temperatures are 25.7 and 8.9°C respectively. Light to moderate frosts are encountered during the winter months.

Perennial ryegrass (cultivar Ellett) was established on 15 September 1992 on a Westleigh soil form (MacVicar *et al* 1977) with an average depth of 300 mm and a clay content of 35%. Shallow soils with high clay contents are not conducive to excellent drainage conditions, a requirement that should be satisfied for good pasture performance from perennial ryegrass (Goodenough *et al*. 1991). Drainage was, however, improved by the establishment of contour banks on the experimental site.

The experimental site was located on a north-east facing aspect with a 6% slope. For the warmer areas of South Africa (which would include the study area), it is generally advised that perennial ryegrass be established on cooler, south-facing slopes (Goodenough *et al*. 1991). Barker *et al*. (1993) acknowledged that in much of New Zealand's dry hill country, improved pasture species (e.g. perennial ryegrass) do not persist well on sunny, north-facing aspects where lack of soil moisture and high temperatures are factors limiting plant survival. In addition to temperature, it has also been found that evapotranspiration is higher on north than on south-facing slopes in New Zealand (Lambert & Roberts 1976). Such effects (temperature and evapotranspiration) are expected to be more pronounced on north-facing aspects under the sub-tropical conditions of South Africa. The site used for this study (which was the only available area on the research farm) was, therefore, less than ideal for the cultivation of perennial ryegrass and the trial would set a severe test for the species.

The whole experimental site was treated equally as far as soil fertility and irrigation were concerned. Soil nutrient status was maintained at > 20 mg L^{-1} and > 150 mg L^{-1} for P and K, respectively (Manson *et al.* 1990). A soil test conducted prior to establishment revealed that neither P, K nor soil acid saturation were limiting factors (Table 3.1). A N:P:K 'pop up' dressing of 250 kg ha^{-1} (2:3:2 (22)) was applied at establishment. Thereafter, N was applied at 480 kg N ha^{-1} $annum^{-1}$, administered as 12 dressings (40 kg N ha^{-1} $month^{-1}$). Irrigation was applied at 25 mm $week^{-1}$, usually as two applications of 12.5 mm every three to four days during the hot summer months (October to March).

Table 3.1 Results of soil tests conducted for the grazing trial

Sample density (g ml^{-1})	P	K	Ca	Mg	Acid Sat. (%)	pH (KCl)
	........mg L^{-1}.........					
1) 1.12	29	239	1487	376	0.9	4.76
2) 1.12	23	254	1810	304	1.0	4.56

1) test conducted August 1992
2) test conducted August 1993

3.2.2 Treatments

Motazedian and Sharrow (1986) reported that much pasture research is conducted on the effects of varying defoliation intensity or varying defoliation frequency on various measurable parameters (e.g. DM production). Both intensity and frequency, however, are rarely simultaneously applied over a range of values in such a way that their interaction can be evaluated. This study adopted grazing defoliation treatment combinations based on: 1) the period of absence of animals from the pasture (i.e. the period over which the pasture recovers); and 2) the residual herbage remaining after grazing (i.e. an indication of the defoliation intensity). Combinations of these were varied between seasons depending on the expected pasture performance within a season

(Goodenough *et al.* 1991). Seasons were defined on the long-term maximum and minimum temperatures for Ukulinga (Table 3.2).

One treatment comprised the current recommended guideline (Goodenough *et al.* 1991) as far as pasture utilization is concerned and, therefore, served as the 'control' treatment. The effects of this treatment, however, have never been formally quantified. Other treatments were extremes of this. These included various combinations of grazing frequency (days) (HF, MF and LF = high, medium and low frequency, respectively) and grazing intensity (kg DM ha^{-1}) (HI, MI and LI = high, medium and low intensity, respectively), applied using rotational grazing. A continuous grazing system (CG), at the MI level, was also applied (Table 3.3).

3.2.3 Experimental design and field lay-out

The six treatments were replicated four times and randomly allocated to 24 plots (randomized blocks design), each 20 m X 20 m (400 m^2) (Figure 3.1).

3.2.4 Grazing management on the trial

Sheep were used to graze the herbage to the desired defoliation intensity. Sheep numbers at each grazing were adjusted so that grazing could be completed in 24 or 48 hours, depending on the herbage available. Total pasture DM (kg ha^{-1}) was determined using the pasture disc meter (Bransby & Tainton 1976) (see section 3.4.2 for more details). The residual herbage to remain after a grazing session (as defined by the treatment) was subtracted from the total estimated using the pasture disc meter. The remaining herbage DM was then assigned to an estimated number of sheep of known mass, based on the assumption that sheep consume approximately 3% of their body mass per day (NRC 1985; McDonald *et al.* 1988). This estimate of sheep numbers required

Table 3.2 Long-term (37 years data) average monthly maximum and minimum temperatures for Ukulinga, and average monthly maximum and minimum temperatures during the trial

Month	Season	Long-term Max(°C)	Long-term Min(°C)	1992 Max (°C)	1992 Min (°C)	1993 Max (°C)	1993 Min (°C)	1994 Max (°C)	1994 Min (°C)
August	Spring	22.1	10.1	-	-	22.2	10.6	22.3	9.8
September		23.3	11.6	24.8	12.3	26.1	13.4	25.8	13.5
October	Early	23.1	12.7	26.5	12.7	23.4	14.2	-	-
November	summer	23.7	14.2	27.4	14.5	26.0	14.8	-	-
December	Mid	25.5	15.6	27.1	16.5	25.6	16.3	-	-
January	summer	26.0	16.6	-	-	28.3	17.1	26.4	16.9
February	Late	26.2	16.8	-	-	27.2	16.7	26.6	16.8
March	summer	25.9	16.0	-	-	26.7	16.1	26.7	16.3
April	Autumn	24.3	13.7	-	-	25.5	13.3	25.4	14.7
May		22.4	11.2	-	-	22.5	11.2	24.2	11.5
June	Winter	20.5	9.0	-	-	21.6	8.8	21.1	8.8
July		20.8	8.9	-	-	22.7	10.2	20.8	7.6

Table 3.3 Treatment combinations for different seasons of the year

Treatment	Spring Abs (days)	Spring Res (kgha⁻¹)	Summer Abs (days)	Summer Res (kgha⁻¹)	Autumn Abs (days)	Autumn Res (kgha⁻¹)	Winter Abs (days)	Winter Res (kgha⁻¹)
LFHI	28.0	500	21.0	650	28.0	500	35.0	350
HFHI	14.0	500	7.0	650	14.0	500	21.0	350
MFMI[1]	21.0	750	14.0	900	21.0	750	28.0	600
LFLI	28.0	1000	21.0	1150	28.0	1000	35.0	850
HFLI	14.0	1000	7.0	1150	14.0	1000	21.0	850
CG	3.5	750	3.5	900	3.5	750	3.5	600

Note: [1] is the current recommendation
Spring = August to September
Summer = October to March
Autumn = April and May
Winter = June to July
Abs = days absent from the pasture
Res = residual herbage after grazing (kg DM ha^{-1})

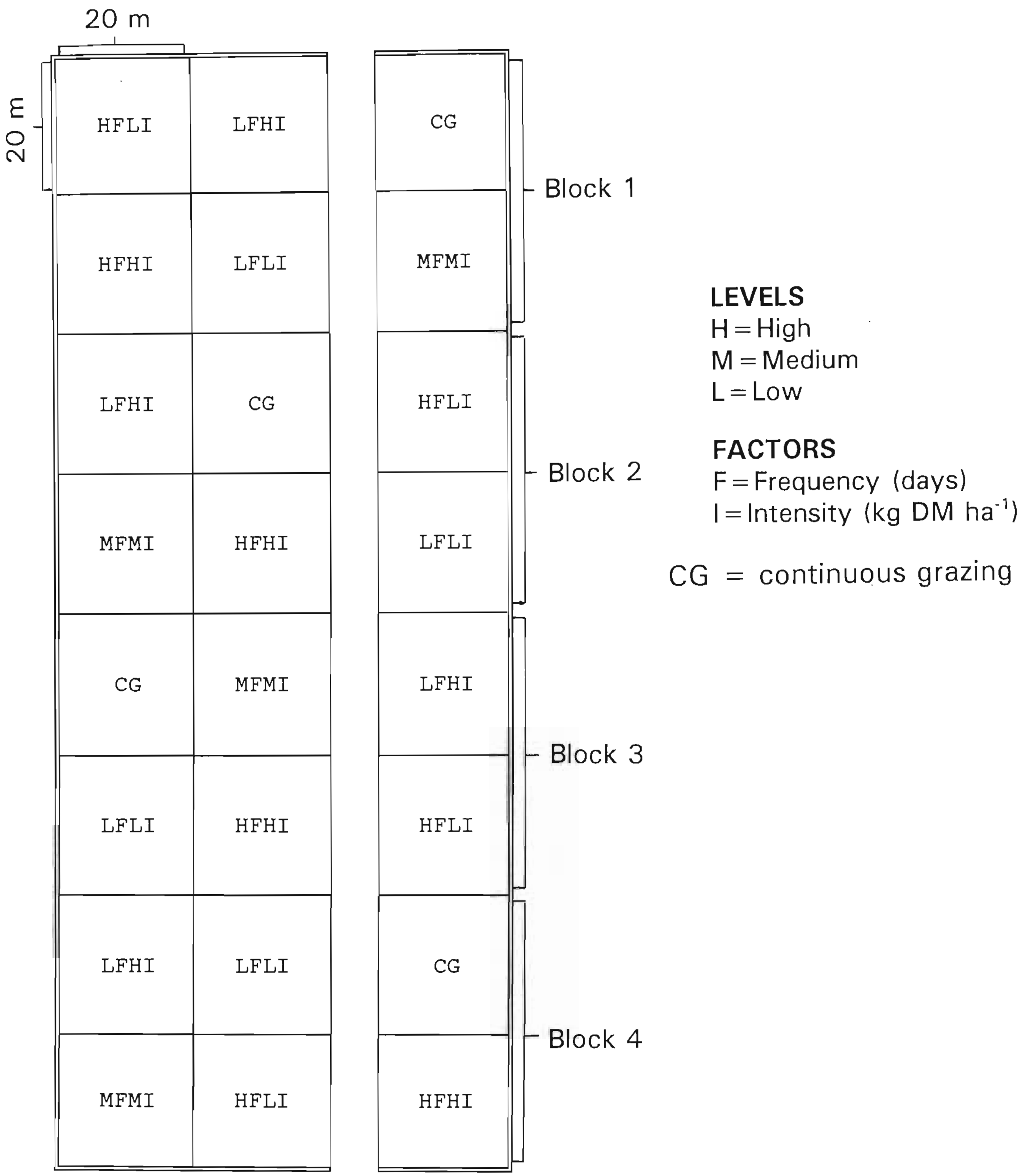


Figure 3.1 Field lay-out of the six grazing treatments.

to achieve a defined defoliation intensity was conservatively applied so that sheep would not graze below this level. The day after a grazing period, the pasture disc meter was used to reassess the remaining herbage and additional sheep were reintroduced to the pasture (only if necessary) to achieve a defoliation intensity within approximately 100 kg DM ha^{-1} of the defined grazing intensity.

The same nucleus group of sheep was rotated across all treatments so that these sheep remained accustomed to consuming perennial ryegrass. Occasionally, during periods of accelerated pasture growth, additional sheep were added to achieve the desired defoliation intensities. These sheep were first preconditioned to ryegrass by grazing them along the passageways of the trial. These passageways were treated exactly as the plots were with respect to fertilizer and irrigation.

While on the pasture, animals had free access to water and no additional supplementation was provided. Apart from weighing the sheep regularly (twice a month) to aid in calculating stock numbers to achieve target defoliation intensities, no animal production records were taken. Animal production parameters were not taken because the quantification of sward parameters was viewed as the first priority in addressing perennial ryegrass management under sub-tropical conditions.

3.3 Population dynamics

3.3.1 Introduction

Rates of tiller appearance, growth and death determine production and persistence of perennial ryegrass (Korte *et al.* 1982). A knowledge of tiller population dynamics can assist interpretation of agronomic studies, and provide basic information for the improvement of pasture management. It is, therefore, believed that the results of this study could lead to principles which can be applied to the grazing management of perennial ryegrass under sub-tropical conditions. The broad objective of this investigation was, therefore, to monitor the tiller population dynamics of perennial ryegrass.

An extensive review by Korte (1986) on field studies of tillering in perennial ryegrass in New Zealand revealed that the relative importance of tillering in different seasons (even for temperate situations) has not been adequately elucidated. As far as the author is aware, there are no similar demographic data for perennial ryegrass under the sub-tropical conditions of South Africa. Therefore, only comparisons between data for this study (in a sub-tropical environment) and data from temperate environments are possible.

3.3.2 Sampling procedure

A grass sward, comprising a population of tillers, is not a stable entity, but is in a continual state of flux (Jewiss 1981). As tillers appear and die throughout the year, the age structure of tillers varies from month to month. Monthly tiller counts give no indication of this. Therefore, counts of new tillers which appear and of those which die each month must be taken into account in the assessment of the structure and development of the sward. For these reasons, measurements of the size of the population must be related to the time of year, recent environmental conditions and the time within a growth period relative to the last defoliation. If this is not the case then such measures have relatively little meaning. The objectives of this study required that the nature of the sward be described by records of its status at a series of points in time. This included measures of its state at any one time as well as the rate of change which may have occurred in the sward between measurements.

3.3.2.1 Non-destructive sampling

A review by Davies (1981) reports that the total area marked in different studies have varied from 697 to 3 716 cm^2 and the frequency of marking from once weekly to once every four weeks. In addition, coefficients of variation (CV) of the number of new tillers appearing (and for those dying) on a unit area of 100 cm^2 average out at between 50 and 58%. Davies (1981) also reported that one person can mark and record an area of 100 cm^2 in ryegrass in 30 minutes.

In this study, all tillers within four randomly placed fixed quadrats per plot (10 cm diameter; 78.54 cm^2) were marked (October 1992) using coloured plastic-coated wire. These tillers' subsequent life histories were followed at monthly intervals. During the observation period, new un-tagged tillers were marked while marked dead tillers were un-tagged and recorded. Different colours were used at each observation period to identify the new tillers. This approach follows that adopted by previous researchers (Table 3.4).

Quadrats were located within each plot by means of a stratified random sampling approach. The whole plot was first sub-divided into four areas and one quadrat randomly located within each area.

Table 3.4 Some examples of studies that made use of non-destructive sampling to monitor perennial ryegrass tiller population dynamics

Reference	Quadrat size	Number of quadrats per treatment
Korte *et al.* (1982)	10.2 cm diameter	20
Korte *et al.* (1984)	10.2 cm diameter	16
Korte (1986)	10.2 cm diameter	20
Korte *et al.* (1987)	10.2 cm diameter	16
L'Huillier (1987)	10.0 cm diameter	32
Hongwen *et al.* (1990)	6.5 cm diameter	9

Justification for adopting four quadrats (10 cm diameter) per plot, giving a total of 16 quadrats per treatment (four replications), was based on the following:

1) such sampling fell within the sampling range of previous studies addressing similar objectives (Table 3.4);
2) from a practical point it was considered desirable to accomplish monthly marking of tillers within four to six days (six treatments each represented by 16 quadrats gave 96 quadrats or approximately 48 hours of sampling time); and
3) a pilot study, using destructively harvested data from a one year old perennial ryegrass pasture located at Cedara Research Station (altitude 1 076 m, 29° 32′ S; 30° 17′E) approximately 25 km from the study site, revealed that acceptable (Davies 1981) CV's of between 15 and 25% for total tiller densities could be achieved from 16 quadrats having a diameter of 10 cm (Figure 3.2).

3.3.2.2 Tiller classification

The following classification of tillers applied to the non-destructive sampling method of this study. Firstly, tillers were described as either dead or alive. Vegetative tillers (tillers not having elongated internodes) were classed as dead once they had no greenish-white leaves remaining inside the sheath and

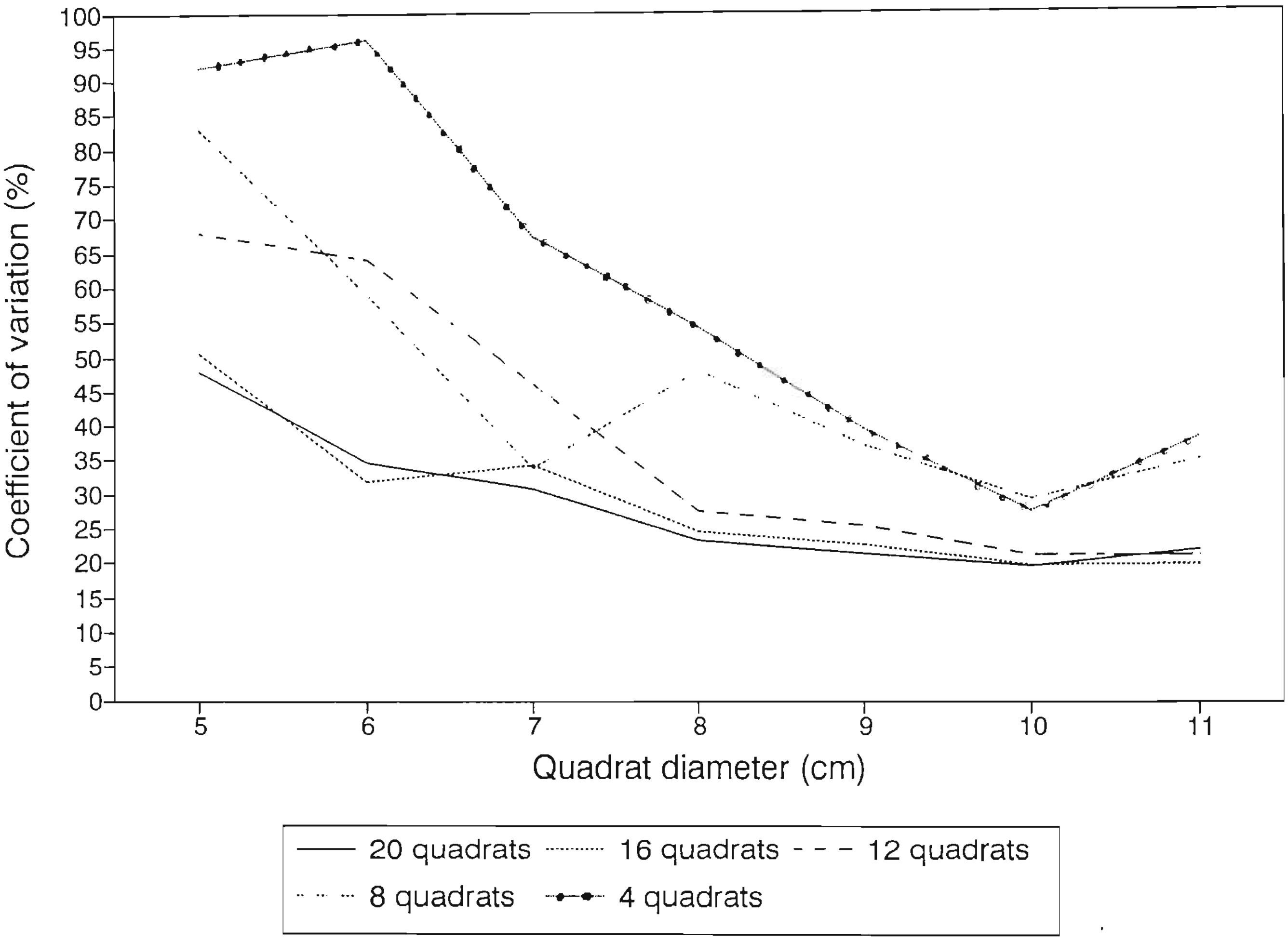


Figure 3.2 The effect of quadrat size and quadrat number on the coefficient of variation for total perennial ryegrass tiller population densities.

were brown and withered in appearance. Reproductive tillers (tillers which have elongated internodes) were classified as dead when the stem was brown and sapless.

Live tillers were then categorized into vegetative, reproductive or aerial tillers. An aerial tiller was defined as one which arose from a node of an extended stem (Thomas 1980) and included both vegetative and reproductive tillers.

3.3.3 Calculations and data analyses

Perennial ryegrass tiller population data were summarized in four stages.

The first considered total tiller population densities over time. Data were summarized on a seasonal basis (see details below) and subjected to analysis of variance (randomized blocks design incorporating nested sub-sampling). Least significance difference (LSD) tests were applied to treatment means (Steel & Torrie 1981).

The second stage examined tiller appearance and death rates. To make treatment comparisons and examine seasonal differences, marked tillers were allocated to 12 age categories for the two year period. These age categories were based on six seasonal periods (Table 3.2) namely 1) early summer (October and November), 2) mid summer (December and January), 3) late summer (February and March), 4) autumn (April and May), 5) winter (June and July), and 6) spring (August and September). Because tillers were monitored on a monthly basis, each seasonal period contained data from two regrowth periods and markings. Tiller appearance rates (TAR) and tiller death rates (TDR) were calculated for each of these seasonal periods using the procedure of Thomas (1980). These were as follows:

1) TAR (tillers day^{-1}) - the total number of tillers marked

during a seasonal period, divided by the days in the period, and

2) TDR (tillers day^{-1}) - the total number of marked tillers dying during a seasonal period, divided by days in the period.

These data were square-root transformed to normalize variables for analysis of variance (Steel & Torrie 1981). Data were then subjected to analysis of variance (randomized blocks design incorporating nested sub-sampling), followed by LSD tests (Steel & Torrie 1981).

For the third stage, a tiller survival matrix was calculated for each treatment, using the 12 age categories outlined previously. Data were first expressed on a proportional basis (i.e. the percentage of tillers alive at the end relative to the beginning of each season). Data were subjected to analysis of variance (randomized blocks design), followed by a LSD tests. Actual tiller numbers per unit area arising in each season were graphically presented to illustrate tiller survival over time for each treatment.

Finally, the production of aerial and reproductive tillers was examined. These data required a square-root transformation before subjecting them to analysis of variance (randomized blocks design), and LSD tests (Steel & Torrie 1981).

3.3.4 Results and discussion

3.3.4.1 Perennial ryegrass tiller densities

Total perennial ryegrass tiller densities for seasonal periods are given in Table 3.5. A distinct pattern of seasonal change in total tiller density was observed for both years, although greater treatment differences were evident in the second than in the first year (Table 3.5). Tiller density declined in mid to late summer (1992/93) and increased during autumn, winter and

Table 3.5 The effect of grazing defoliation on total tiller population densities, calculated for seasonal periods

Seasonal period	LFHI	HFHI	MFMI	LFLI	HFLI	CG	LSD (P=0.05)	Average
	Treatments[1] (tillers m^{-2})							
Early summer (Oct/Nov 1992)	8 123	10 109	8 709	9 868	8 874	8 263	1 756	8 991
Mid summer (Dec/Jan 1992/93)	9 180	10 899	8 747	8 352	9 002	9 104	1 472	9 214
Late summer (Feb/Mar 1993)	8 518	8 072	8 161	9 282	8 594	6 672	1 583	8 217
Autumn (Apr/May 1993)	10 288	8 874	8 327	10 402	9 409	8 072	1 805	9 229
Winter (Jun/Jul 1993)	11 281	9 575	9 664	10 886	10 899	9 753	1 623	10 343
Spring (Aug/Sep 1993)	14 464	13 611	12 299	12 554	13 267	13 407	1 427	13 267
Early summer (Oct/Nov 1993)	12 681	11 803	10 632	9 791	11 561	13 203	1 387	11 612
Mid summer (Dec/Jan 1993/94)	11 370	9 511	8 174	8 938	9 384	10 835	1 569	9 702
Late summer (Feb/Mar 1994)	9 804	5 628	4 443	7 321	6 404	7 779	1 762	6 897
Autumn (Apr/May 1994)	11 179	5 704	4 418	8 951	5 921	8 174	1 623	7 391
Winter (Jun/Jul 1994)	12 261	6 379	5 322	10 759	6 863	8 989	1 529	8 429
Spring (Aug/Sep 1994)	15 966	9 715	8 021	13 917	9 562	11 255	1 478	11 406
Average	11 260	9 157	8 067	10 085	9 145	9 626		9 558

[1] LEVELS
H = High
M = Medium
L = Low

FACTORS
F = Frequency
I = Intensity
CG = continuous grazing

spring. The same decline was apparent in early to late summer of the second year (1993/94), with an increase again during autumn, winter and spring.

During 1992/93, total perennial ryegrass tiller densities ranged from 6 672 tillers m^{-2} (CG) during late summer to 14 464 tillers m^{-2} (LFHI) during spring. In 1993/94, total tiller density ranged from 4 418 tillers m^{-2} (MFMI) in autumn to 15 966 tillers m^{-2} (LFHI) during spring (Table 3.5). The overall tiller densities observed for these sheep grazed swards appear to be lower than those estimated under temperate conditions. Large differences, however, exist in tiller densities for pastures grazed by sheep versus those grazed by cattle. Perennial ryegrass tiller densities in pastures grazed by cattle may be as high as 16 000 tillers m^{-2}, but usually range from 2 000 to 6 000 tillers m^{-2} (L'Huillier 1987; Da Silva *et al.* 1993; Thom & Bryant 1993). Alternatively, tiller densities for swards continuously grazed by sheep may be as high as 50 000 tillers m^{-2} (King *et al.* 1988), but are usually in the range of 10 000 to 30 000 tillers m^{-2} (Chapman *et al.* 1983; Barthram *et al.* 1992). These slightly lower tiller densities (Table 3.5) may be a function of the sub-tropical conditions, and particularly the hot summer temperatures (mean monthly maximum up to 28 °C; Table 3.2) experienced during this trial. For temperate grass species such as perennial ryegrass, 25 °C is the optimum temperature for 'normal' physiological functioning. At 25 to 30 °C growth slows down, while at temperatures above 30 °C growth and development may cease altogether (Cooper & Tainton 1968; Vogel *et al.* 1978).

Seasonal fluctuations in total tiller density were lowest for those treatments infrequently defoliated (i.e. LFHI and LFLI) (Table 3.5). This suggests that low rather than medium to high defoliation frequencies impart a greater stability on total perennial ryegrass tiller densities. While only a few significant ($P \leq 0.05$) treatment differences were observed during

1992/93, there were many during 1993/94, particularly from February to September 1994. During this period (February to September 1994), the LFHI and LFLI treatments emerged with considerably higher ($P \leq 0.05$) tiller densities than the HFHI, MFMI, HFLI and CG treatments. From these data it appears that, under sub-tropical conditions, a low defoliation frequency favours higher tiller densities more than medium to high defoliation frequencies. In addition, the LFHI treatment produced the highest (often significantly so, $P \leq 0.05$) tiller densities for most seasons under consideration (except during the early to late summer, and spring periods of 1992/93).

Under temperate conditions, perennial ryegrass tiller density tends to increase with frequent and intense defoliation (Grant *et al.* 1981; Korte *et al.* 1982; Baker & Leaver 1986; Korte 1986; Clark 1993b) and decrease with infrequent and lenient defoliation (Tainton 1974; Pineiro & Harris 1978; Grant *et al.* 1983; Lowe & Bowdler 1988). In this study, however, frequent defoliation, particularly during the summer periods, produced lower tiller densities than infrequent defoliation (Table 3.5). Intense defoliation did produce high tiller densities, but only when coupled with a lower frequency defoliation (e.g. LFHI).

In considering perennial ryegrass tiller densities (Table 3.5), it would appear that the spring period is the most crucial season for manipulating tiller densities by grazing management. While significant ($P \leq 0.05$) treatment differences were evident during spring, all treatments demonstrated a similar pattern of higher tiller densities for spring than any other season. Thom and Bryant (1993) reported that variation in spring grazing management was likely to have the most pronounced effect on pasture tiller density. Under temperate conditions, high frequency coupled with intensive defoliations stimulated high tiller densities. This is in contrast to these data for sub-tropical conditions where the LFHI treatment gave the highest spring tiller density over two years (Table 3.5).

Differences in tiller density may arise from a difference in tillering rate and/or in the tiller death rate (Korte *et al.* 1982). Reasons for the observed differences in total tiller densities for this study are examined in section 3.3.4.2.

3.3.4.2 Tiller appearance and death rates

The TAR and TDR are presented in Tables 3.6 and 3.7, while the net difference between TAR and TDR are presented in Table 3.8.

Apart from the initial period of sward establishment (early summer 1992), TAR were highest between autumn and spring and lowest during the entire summer period for both years (Table 3.6). Excluding the early summer period for 1992/93, TAR ranged from 10 tillers m^{-2} day^{-1} (LFLI) in mid summer to 86 tillers m^{-2} day^{-1} (HFHI) in spring. During 1993/94, TAR ranged from 9 tillers m^{-2} day^{-1} (MFMI) in late summer to 79 tillers m^{-2} day^{-1} (LFHI) in spring.

There was a tillering 'flush' from autumn to spring, relative to the summer periods. This 'flush' reached a peak in spring (ranging from 59 to 83 and 54 to 79 tillers m^{-2} day^{-1} for 1992/93 and 1993/94, respectively), with a minor trough in winter (ranging from 23 to 41 and 28 to 50 tillers m^{-2} day^{-1} for 1992/93 and 1993/94, respectively) (Table 3.6). Contrary to these results, L'Huillier (1987) reported low tillering rates for grazed perennial ryegrass swards during autumn (27.8 tillers m^{-2} day^{-1}) in New Zealand and found these to be similar to those estimated for the winter period (27.7 tillers m^{-2} day^{-1}). These results of relatively low TAR (L'Huillier 1987) were perhaps due to cattle rather than sheep grazing the pastures. Sheep grazed pastures generally exhibit higher TAR than cattle grazed pastures (Chapman *et al.* 1983; Da Silva *et al.* 1993), presumably because sheep graze more intensively than cattle (Thom & Bryant 1993).

Table 3.6 Effect of treatments on tiller appearance rates (TAR) calculated for seasonal periods. Data are square-root transformed and LSD's (P=0.05) are presented, while untransformed treatment means are given in brackets

Seasonal period	LFHI	HFHI	MFMI	LFLI	HFLI	CG	LSD (P=0.05)	Average
	Treatments[1] (tillers m^{-2} day^{-1})							
Early summer (Oct/Nov 1992)	10.44 (109)	11.62 (135)	10.86 (118)	11.53 (133)	10.91 (119)	10.54 (111)	1.25	121
Mid summer (Dec/Jan 1992/93)	5.29 (28)	5.39 (29)	4.24 (18)	3.16 (10)	4.47 (20)	5.48 (30)	1.05	23
Late summer (Feb/Mar 1993)	3.46 (12)	4.08 (16)	4.00 (16)	3.87 (15)	4.47 (15)	5.48 (19)	1.01	16
Autumn (Apr/May 1993)	6.63 (44)	6.08 (37)	5.20 (27)	5.74 (33)	5.39 (29)	7.07 (50)	0.94	37
Winter (Jun/Jul 1993)	5.92 (35)	5.48 (30)	5.83 (34)	4.80 (23)	6.08 (37)	6.40 (41)	1.18	33
Spring (Aug/Sep 1993)	8.43 (71)	9.27 (86)	8.03 (64)	7.68 (59)	7.87 (62)	9.11 (83)	1.22	71
Early summer (Oct/Nov 1993)	4.47 (20)	5.48 (30)	4.90 (24)	4.41 (20)	5.20 (27)	5.92 (35)	0.68	26
Mid summer (Dec/Jan 1993/94)	5.57 (31)	4.59 (21)	4.47 (20)	5.39 (29)	4.80 (23)	5.62 (31)	0.91	26
Late summer (Feb/Mar 1994)	5.66 (32)	3.32 (11)	3.11 (9)	4.58 (21)	3.46 (12)	3.74 (14)	0.78	17
Autumn (Apr/May 1994)	7.75 (60)	6.03 (36)	5.10 (26)	7.21 (52)	5.13 (26)	5.57 (31)	0.85	39
Winter (Jun/Jul 1994)	7.07 (50)	5.48 (30)	5.29 (28)	6.78 (46)	5.39 (29)	5.48 (30)	1.19	36
Spring (Aug/Sep 1994)	8.89 (79)	8.49 (72)	7.35 (54)	8.06 (65)	7.48 (56)	7.68 (59)	0.75	64
Average	48	44	37	42	38	45		42

[1]see footnote to Table 3.5

Table 3.7 Effect of treatments on tiller death rates (TDR) calculated for seasonal periods. Data are square-root transformed and LSD's (P=0.05) are presented, while untransformed treatment means are given in brackets

Seasonal period	LFHI	HFHI	MFMI (tillers m^{-2} day^{-1})	LFLI	HFLI	CG	LSD (P=0.05)	Average
	Treatments[1]							
Early summer (Oct/Nov 1992)	0.82 (1)	0.41 (0)	1.37 (2)	1.17 (1)	0.82 (1)	0.92 (1)	0.78	1
Mid summer (Dec/Jan 1992/93)	3.22 (10)	3.99 (16)	4.17 (17)	4.27 (18)	4.22 (18)	3.99 (16)	0.93	16
Late summer (Feb/Mar 1993)	4.81 (23)	7.94 (63)	5.07 (26)	4.07 (17)	4.68 (22)	7.72 (60)	1.14	35
Autumn (Apr/May 1993)	3.80 (14)	4.85 (24)	4.92 (24)	3.80 (14)	3.94 (15)	5.17 (27)	1.08	20
Winter (Jun/Jul 1993)	4.30 (18)	4.27 (18)	3.42 (12)	3.85 (15)	3.48 (12)	3.66 (13)	1.23	15
Spring (Aug/Sep 1993)	4.25 (18)	4.32 (19)	4.49 (20)	5.13 (26)	4.61 (21)	4.70 (22)	1.03	21
Early summer (Oct/Nov 1993)	6.83 (47)	7.75 (60)	7.20 (52)	7.93 (63)	7.44 (55)	6.20 (38)	1.10	53
Mid summer (Dec/Jan 1993/94)	7.38 (55)	7.69 (59)	6.94 (48)	6.58 (43)	7.69 (59)	8.39 (70)	0.93	56
Late summer (Feb/Mar 1994)	7.57 (57)	8.70 (76)	8.43 (71)	6.93 (48)	7.86 (62)	8.06 (65)	0.98	63
Autumn (Apr/May 1994)	5.92 (35)	5.53 (31)	5.15 (27)	4.98 (25)	5.85 (34)	4.94 (24)	1.13	29
Winter (Jun/Jul 1994)	4.24 (18)	4.32 (19)	3.60 (13)	3.99 (16)	3.66 (13)	4.04 (16)	0.89	16
Spring (Aug/Sep 1994)	3.99 (16)	4.09 (17)	2.99 (9)	3.51 (12)	3.32 (11)	4.61 (21)	0.95	14
Average	26	34	27	25	27	31		28

[1]see footnote to Table 3.5

Table 3.8 Net difference between tiller birth rates (TAR) and tiller death rates (TDR), calculated for seasonal periods. Data are re-scaled (to avoid negative numbers) and square-root transformed and LSD's (P=0.05) are presented, while untransformed treatment means are given in brackets

Seasonal period	Treatments[1] LFHI	HFHI	MFMI (tillers m^{-2} day^{-1})	LFLI	HFLI	CG	LSD (P=0.05)	Average
Early summer Oct/Nov 1992)	13.23 (108)	14.21 (135)	13.53 (116)	14.11 (132)	13.60 (118)	13.30 (110)	1.37	120
Mid summer (Dec/Jan 1992/93)	9.22 (18)	8.94 (13)	8.25 (1)	7.68 (-8)	8.31 (2)	9.01 (14)	1.13	7
Late summer (Feb/Mar 1993)	7.48 (-11)	4.47 (-47)	7.55 (-10)	8.06 (-2)	7.75 (-7)	5.10 (-41)	1.23	-20
Autumn (Apr/May 1993)	9.85 (30)	8.94 (13)	8.37 (3)	9.27 (19)	8.96 (14)	9.49 (23)	1.09	17
Winter (Jun/Jul 1993)	9.17 (17)	9.43 (22)	9.54 (24)	8.66 (8)	9.59 (25)	9.75 (28)	1.16	21
Spring (Aug/Sep 1993)	10.95 (53)	11.58 (67)	10.54 (44)	10.03 (33)	10.39 (41)	11.31 (61)	1.07	50
Early summer (Oct/Nov 1993)	6.32 (-27)	6.08 (-30)	6.24 (-28)	4.90 (-43)	6.24 (-28)	7.95 (-3)	1.13	-27
Mid summer (Dec/Jan 1993/94)	6.56 (-24)	5.39 (-38)	6.25 (-28)	7.28 (-14)	5.57 (-36)	5.29 (-39)	0.98	-30
Late summer (Feb/Mar 1994)	6.48 (-25)	1.41 (-65)	2.24 (-62)	6.32 (-27)	5.20 (-40)	3.96 (-51)	1.22	-45
Autumn (Apr/May 1994)	9.59 (25)	8.49 (5)	8.12 (-1)	9.69 (27)	7.68 (-8)	8.60 (7)	0.91	9
Winter (Jun/Jul 1994)	9.95 (32)	9.38 (21)	9.06 (15)	9.85 (30)	9.17 (17)	8.97 (14)	1.02	22
Spring (Aug/Sep 1994)	11.40 (63)	11.04 (55)	10.58 (45)	10.95 (53)	10.58 (45)	10.25 (38)	1.19	50
Average	22	13	10	17	12	13		15

[1]see footnote to Table 3.5

Also contrary to the findings of this study, Korte (1986) and L'Huillier (1987) reported that there was little evidence to suggest that a tillering 'flush' occurred during autumn in perennial ryegrass under the temperate conditions of New Zealand. Alternatively, Korte *et al*. (1985) reported two periods of active tillering in perennial ryegrass in New Zealand. The first was in spring (before the onset of the reproductive phase) and the second after interruption (by defoliation) of reproductive development in late spring - early summer. Also, the second period of tillering occurs in early summer in frequently grazed swards or cut swards in New Zealand. In this regard, Matthew *et al*. (1993) proposed two pathways of perennation in perennial ryegrass for New Zealand's temperate conditions: 1) production of daughter tillers from flowering tillers (reproductive pathway); and 2) perennation by tillering from surviving non-flowering tillers (vegetative pathway). Rotational lenient grazing favoured the reproductive pathway while the vegetative pathway was favoured by a more frequent and severe grazing defoliation programme.

On the other hand, studies conducted in the United Kingdom (Langer 1963; Garwood 1969) have identified periods of rapid tillering during both spring and autumn. Garwood (1969) reported that tiller numbers increased rapidly in autumn and again in late winter or early spring, and then declined until mid summer. Considering the findings of this review, it would appear that not as much importance is placed on autumn tillering in New Zealand as in the United Kingdom. Given the level of TAR during autumn in my own study (ranging from 27 to 50 and 26 to 60 tillers m^{-2} day^{-1} for 1992/93 and 1993/94, respectively) (Table 3.6), it is believed that this period (and the spring period) should be considered important from a management view under sub-tropical conditions. The tillering 'flushes' observed from autumn to spring must be considered important because these resulted in an almost doubling of tiller densities after the late summer period

(Table 3.5). These large increases in tiller densities over the autumn to spring period were also a result of low TDR during this time (Table 3.7), which in turn resulted in large net gains in tiller numbers (Table 3.8).

During 1992/93, treatments frequently and intensely defoliated (e.g. HFHI and CG) generally had higher (often significantly so, $P \leq 0.05$) TAR than the other treatments (e.g. LFHI, MFMI, LFLI and HFLI) (Table 3.6). The LFLI treatment consistently (except during early summer and autumn) had the lowest (often significantly so, $P \leq 0.05$) TAR relative to other treatments. These results are substantiated by the findings of numerous researchers (e.g. Grant *et al.* 1981; Korte *et al.* 1982; Lowe & Bowdler 1988) who have shown that high frequency and intensity defoliations, whether by cutting or grazing, stimulate high TAR. An accelerated rate of tillering is made possible by faster rates of leaf appearance, since the formation of tiller buds is associated with the formation of leaves (Mitchell 1953; Davies 1981). Mitchell (1953) also reported that reducing light, or increasing temperature, or both, tended to inhibit tiller development from the basal nodes of a sward. Rates of tillering can therefore be influenced by management, and tend to be highest on severely grazed swards. An important aspect of accelerated leaf appearance rate on intensively grazed swards is its role in increasing the number of tiller bud sites and hence the potential tiller number of such swards (Grant *et al.* 1981; Davies & Thomas 1983). These authors report that on hard grazed plots, the increased number of tiller bud sites, coupled with the greater light penetration, resulted in a rapid increase in tiller populations.

Initially (early to mid summer 1992/93), high frequency and intensity defoliations stimulated high TAR (Table 3.6). Thereafter, however, treatments frequently and intensely defoliated (HFHI and CG) no longer produced the highest TAR.

Here, treatments infrequently defoliated (e.g. LFHI and LFLI), and particularly when coupled with intensive defoliation (LFHI), produced the highest (usually significantly so, $P \leq 0.05$) TAR relative to the other treatments. Considering TAR from the 1992/93 to 1993/94 year it was interesting to note that the LFHI and LFLI treatments showed an increase in TAR while the HFHI and CG treatments declined in TAR, particularly from late summer to spring 1994. It would appear that a high level of defoliation frequency and intensity begins to decrease the tillering ability of perennial ryegrass after one and a half years under sub-tropical conditions.

Excluding the initial period of sward establishment (early summer 1992), TDR were highest during the entire summer period and lowest for the autumn to spring periods for both years (Table 3.7). Apart from the early summer period for 1992/93, TDR ranged from 10 tillers m^{-2} day^{-1} (LFHI) during mid summer to 63 tillers m^{-2} day^{-1} (HFHI) late summer. During 1993/94, TDR ranged from 9 tillers m^{-2} day^{-1} (MFMI) in spring to 76 tillers m^{-2} day^{-1} (HFHI) during late summer. These results suggest perennial ryegrass swards are more stable and have lower TDR during the cooler than the warmer seasons. Korte *et al.* (1982) found that the tiller death rate at two defoliation heights (1-2 cm and 5-6 cm) was not significantly different during the autumn - winter period. The reason cited for this observation was that the appearance of new tillers over this period more than compensated for tiller death. High TAR were also observed for this study during these seasons (Table 3.6).

Total losses of ryegrass plants have been found to be highest in summer and 'animal effects' (i.e. intensive grazing, pulling, dung and urine deposition and trampling) accounted for 51% of the total summer losses (Thom *et al.* 1986). Thom (1991) later reported that defoliation during summer greatly increased the probability of vegetative tiller death. Treatments frequently and intensively defoliated (e.g. HFHI and CG) generally had higher (often significantly so, P≤0.05) TDR than the other treatments (e.g. LFHI, MFMI, LFLI and HFLI), particularly during the mid to late summer periods for both years (Table 3.7). During the autumn, winter and spring periods for both years, there were relatively small differences (P>0.05) in TDR between treatments, indicating that these seasons are more stable (i.e. low TDR) and favour higher tiller densities (Table 3.5) relative to the summer seasons. These results, at least for the autumn to spring periods, are substantiated by previous studies on perennial ryegrass. Defoliation frequency was found to have relatively little effect on seasonal changes in tillering (Korte 1986). Langer *et al.* (1964) found that the general pattern of tillering was little affected by cutting in *Festuca pratensis* (meadow fescue) and *Phleum pratense* (timothy). L'Huillier (1987) also demonstrated that actual seasonal patterns of tillering were not influenced by grazing defoliation treatments. While seasonal patterns of tillering (Table 3.6) and death (Table 3.7) may be largely unaffected by defoliation treatments, the degree of TAR and TDR can be manipulated within a given season by defoliation.

The LFLI treatment had the highest TDR relative to other treatments over the early summer (1993/94) period (in some cases significantly so, P≤0.05) (Table 3.7). Such a treatment may favour the stimulation of high levels of reproductive and aerial tillers which then die after flowering in spring (L'Huillier 1987). In addition, such a treatment may encourage elevated growth apices which become vulnerable to removal during grazing (Tainton 1981). Densities of reproductive and aerial tillers are examined in section 3.3.4.4. Generally, however, treatments more infrequently and/or leniently defoliated (e.g. LFHI, MFMI, LFLI and HFLI) produced the lowest (usually significantly so, P≤0.05) TDR relative to those frequently and intensively defoliated (HFHI and CG).

Considering TDR for the total period, it was noted that all treatments showed an increases in TDR over the summer periods (Table 3.7). This suggests that, under sub-tropical conditions, perennial ryegrass is highly susceptible to mismanagement during summer. Apart from infrequent grazing management (e.g. LFHI and LFLI), careful attention should also be paid to irrigation management during summer. Dry soil conditions are reported to delay an increase in tiller numbers (Garwood 1968; 1969), while drought conditions may also reduce the rate of tillering (Gao & Wilman 1993). Under such conditions it is possible that tiller death rates exceed tiller birth rates.

The patterns for TAR and TDR were complemented by the net difference between these (Table 3.8). During the late summer period for 1992/93, the HFHI and CG treatments showed a higher net loss ($P \leq 0.05$) in tillers than all the other treatments. This pattern was again repeated during the mid to late summer and autumn periods during 1993/94 (Table 3.8). Sward survival depends on tiller replacement to maintain an effective density. While high defoliation frequencies and intensities may stimulate high tillering rates (Grant *et al*. 1981; Korte *et al*. 1982; Lowe & Bowdler 1988), the results of my study have shown that a more stable tiller population (in terms of lower death rates) can be maintained with infrequent defoliations during summer.

The LFLI treatment had a higher net loss (for most comparisons significantly so, $P \leq 0.05$) of tillers than the other treatments during the mid summer of 1992/93 and again during the early summer of 1993/94, presumably because of high reproductive and aerial tiller mortalities. Shading of vegetative tillers and their subsequent death may also have occurred at this time (Hughes and Jackson 1974). Reproductive and aerial tillering patterns will be investigated in section 3.3.4.4.

Generally, however, treatment differences in the net difference between TAR and TDR were small and non-significant (P>0.05) during autumn, winter and spring of 1992/93 and during the winter and spring of 1993/94 (Table 3.8). This supports an earlier argument that perennial ryegrass tiller populations are generally more stable during the cooler than the warmer months.

3.3.4.3 Tiller survival potential

Survival of tillers tagged at the start of the experiment and those tagged in each seasonal period are given in Table 3.9. Tillers originating in different seasons and the way in which these contributed to total tiller density in terms of their survival are illustrated in Figure 3.3.

Tillers tagged at the start of the experiment (early summer 1992/93) survived the longest - from early summer 1992 to autumn 1994 (Table 3.9 & Figure 3.3). This was presumably because this group constituted the original establishment population and was also monitored for the entire trial duration (i.e. two years). Apart from this group of establishment tillers, the survival of tillers originating in mid and late summer (1992/93) and early to late summer (1993/94) was poor in all treatments (Table 3.9 & Figure 3.3). In addition, the HFHI and CG treatments reflected even poorer ($P \leq 0.05$) tiller survival potential for those tillers that originated during the summer periods than those treatments less frequently and/or less intensively grazed (e.g. LFHI, MFMI, LFLI and HFLI) (Table 3.9). Research has shown that the smallest or youngest tiller, irrespective of tiller position, dies first when the whole plant is stressed. These tillers tend to be entirely dependent upon the parent tillers for water and nutritional supplies (Ong 1978). Perennial ryegrass under sub-tropical conditions is presumably stressed in summer due to hot temperatures (Cooper & Tainton 1968; Vogel *et al*. 1978). During the trial, maximum daily temperatures during summer often fluctuated between 30 and 40 °C.

Table 3.9 Survival of tillers in each season (percentage of those present at the beginning of each season which were still alive at the end of that season) for tillers of different seasonal origin

		Season of tiller origin											
		1992/93						1993/94					
Season	Treatments[1]	E sum	M sum	L sum	Aut	Win	Spr	E sum	M sum	L sum	Aut	Win	Spr
E sum	LFHI	97											
	HFHI	92											
	MFMI	98											
	LFLI	99											
	HFLI	99											
	CG	93											
	LSD(0.05)	**9**											
M sum	LFHI	93	87										
	HFHI	91	84										
	MFMI	87	93										
	LFLI	88	99										
	HFLI	89	91										
	CG	83	61										
	LSD(0.05)	**13**	**14**										
L sum	LFHI	84	55	93									
	HFHI	64	38	77									
	MFMI	75	56	99									
	LFLI	79	81	99									
	HFLI	78	64	99									
	CG	71	43	79									
	LSD(0.05)	**16**	**14**	**12**									
Aut	LFHI	80	32	81	97								
	HFHI	57	23	52	96								
	MFMI	67	38	52	94								
	LFLI	72	70	93	98								
	HFLI	72	54	73	96								
	CG	67	36	58	56								
	LSD(0.05)	**17**	**17**	**14**	**13**								
Win	LFHI	75	16	42	93	99							
	HFHI	51	16	28	93	98							
	MFMI	62	36	43	84	98							
	LFLI	67	62	75	92	99							
	HFLI	68	50	54	90	99							
	CG	63	33	42	52	89							
	LSD(0.05)	**17**	**18**	**15**	**13**	**11**							
Spr	LFHI	70	11	19	86	93	96						
	HFHI	47	7	15	86	91	93						
	MFMI	55	31	29	74	86	99						
	LFLI	57	53	51	76	86	97						
	HFLI	59	46	30	82	92	99						
	CG	55	27	23	48	83	74						
	LSD(0.05)	**16**	**13**	**13**	**14**	**12**	**11**						

Table 3.9 continued

Treatments[1]		Season of tiller origin 1992/93						1993/94					
Season		E sum	M sum	L sum	Aut	Win	Spr	E sum	M sum	L sum	Aut	Win	Spr
E sum	LFHI	53	8	11	78	71	84	89					
	HFHI	25	4	4	74	76	86	71					
	MFMI	34	13	20	69	76	86	94					
	LFLI	30	17	47	67	67	82	97					
	HFLI	39	29	21	75	74	82	95					
	CG	32	19	15	44	67	61	73					
	LSD(0.05)	**13**	**14**	**14**	**12**	**13**	**11**	**12**					
M sum	LFHI	37	4	5	66	56	64	71	89				
	HFHI	15	0	3	60	60	68	51	68				
	MFMI	23	9	12	48	52	54	65	91				
	LFLI	20	6	21	40	48	78	66	97				
	HFLI	27	12	8	62	57	59	63	90				
	CG	25	8	7	36	51	44	48	66				
	LSD(0.05)	**15**	**17**	**16**	**12**	**12**	**12**	**13**	**14**				
L sum	LFHI	19	0	0	53	46	56	35	64	93			
	HFHI	4	0	0	31	34	46	26	32	91			
	MFMI	9	8	4	22	25	29	20	61	95			
	LFLI	8	2	17	27	33	65	56	59	99			
	HFLI	13	7	0	41	37	41	42	56	89			
	CG	12	5	0	24	33	31	32	41	77			
	LSD(0.05)	**16**	**18**	**19**	**13**	**14**	**12**	**16**	**14**	**12**			
Aut	LFHI	7	0	0	48	43	50	22	43	85	99		
	HFHI	1	0	0	20	27	31	9	19	81	83		
	MFMI	4	0	0	17	21	23	13	26	83	99		
	LFLI	3	0	8	14	32	58	53	55	90	99		
	HFLI	4	3	0	32	29	31	35	40	74	99		
	CG	3	0	0	19	25	23	26	29	64	84		
	LSD(0.05)	**16**	-	-	**15**	**13**	**13**	**14**	**13**	**13**	**11**		
Win	LFHI	0	0	0	44	40	48	12	24	44	98	98	
	HFHI	0	0	0	14	20	24	7	16	46	88	93	
	MFMI	0	0	0	15	20	20	10	17	64	95	98	
	LFLI	0	0	0	10	31	54	51	53	88	93	98	
	HFLI	0	0	0	30	28	26	31	37	66	95	99	
	CG	0	0	0	15	23	19	22	27	57	82	96	
	LSD(0.05)	-	-	-	**16**	**15**	**14**	**15**	**14**	**14**	**12**	**10**	
Spr	LFHI	0	0	0	38	39	46	5	14	31	91	96	97
	HFHI	0	0	0	10	11	18	4	12	36	79	78	94
	MFMI	0	0	0	13	18	17	7	12	52	93	90	95
	LFLI	0	0	0	8	29	44	44	48	79	90	94	96
	HFLI	0	0	0	29	22	23	25	33	47	93	94	98
	CG	0	0	0	12	20	17	19	24	37	74	70	93
	LSD(0.05)	-	-	-	**17**	**19**	**13**	**14**	**17**	**16**	**13**	**12**	**9**

[1]see footnote to Table 3.5

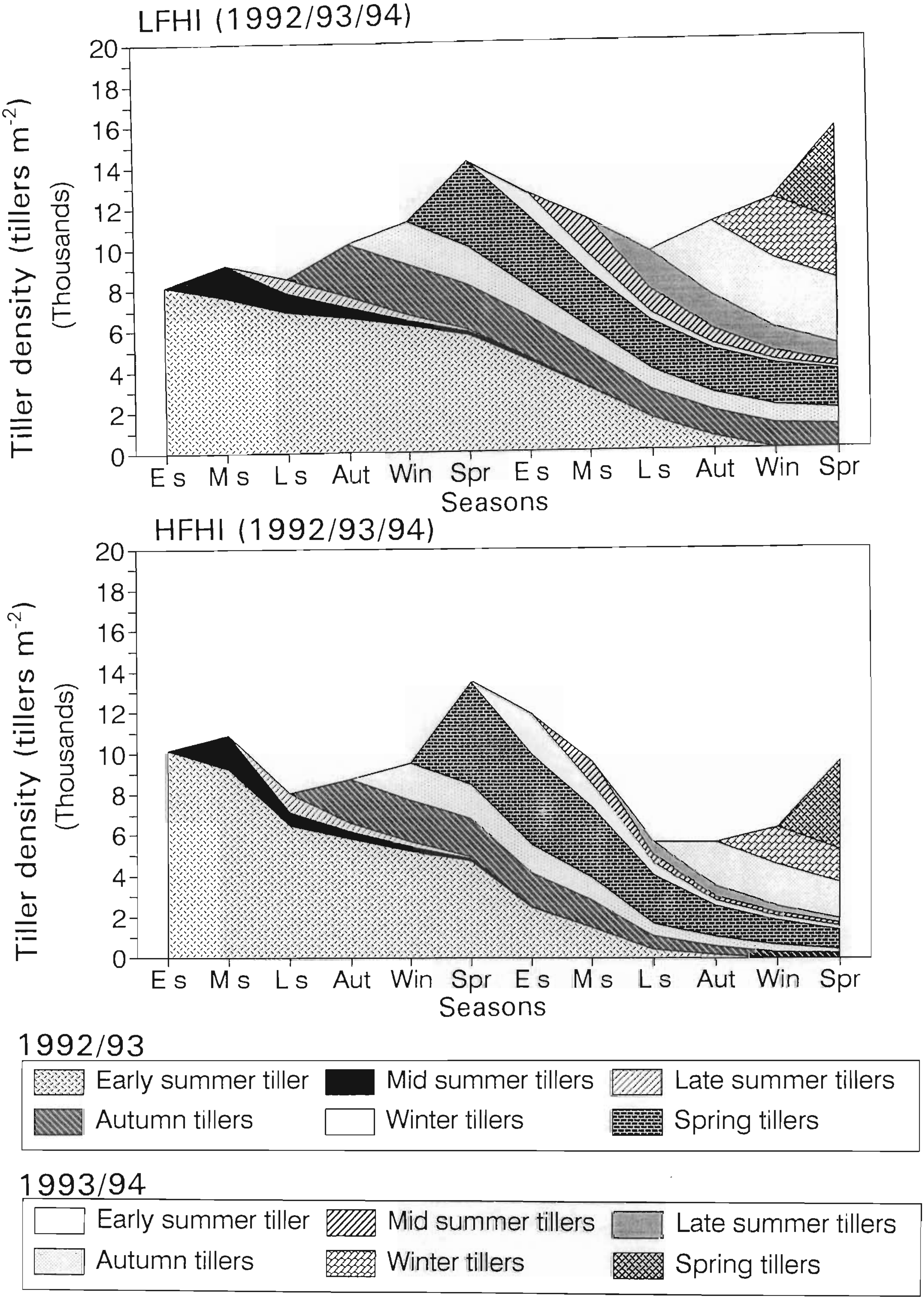
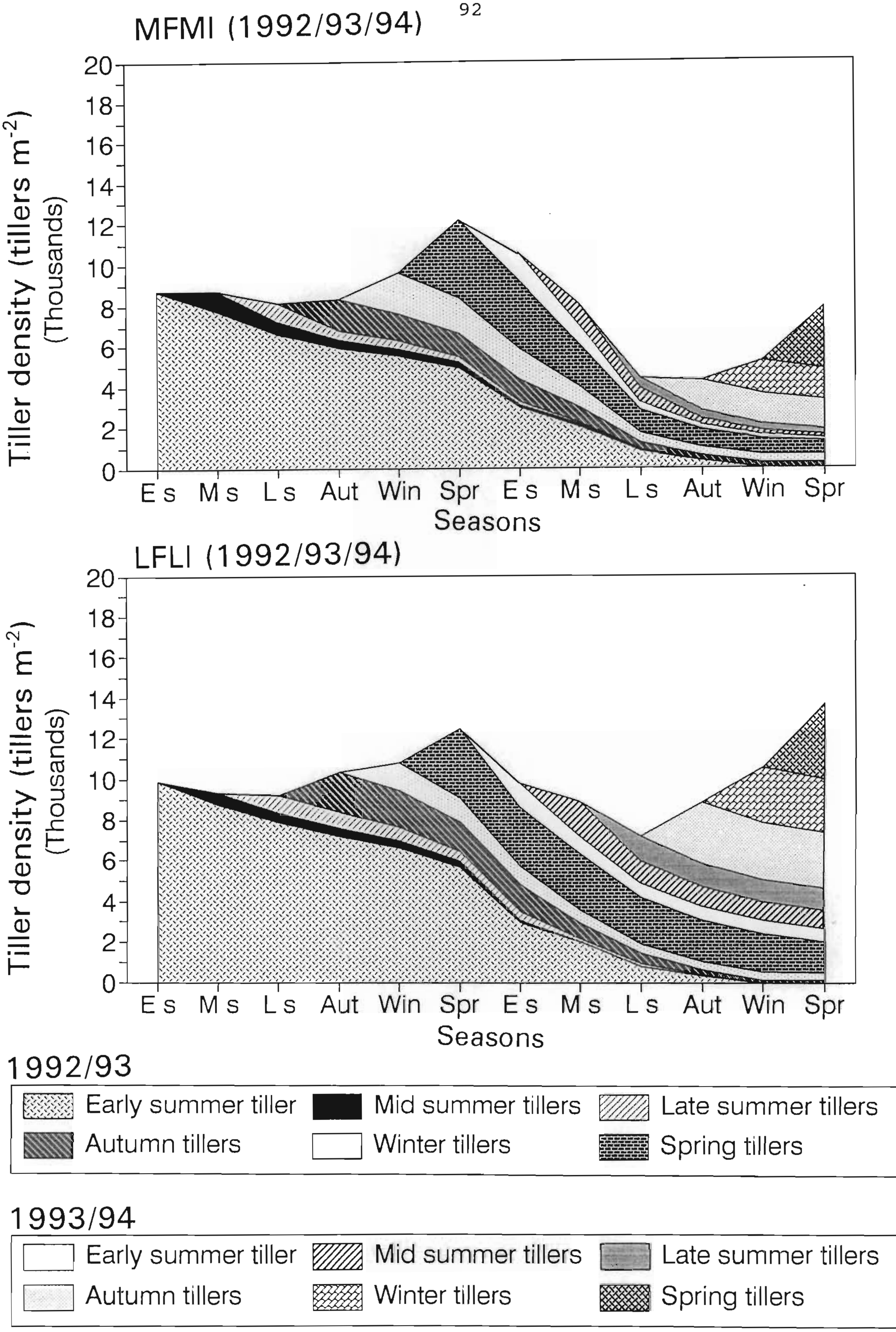
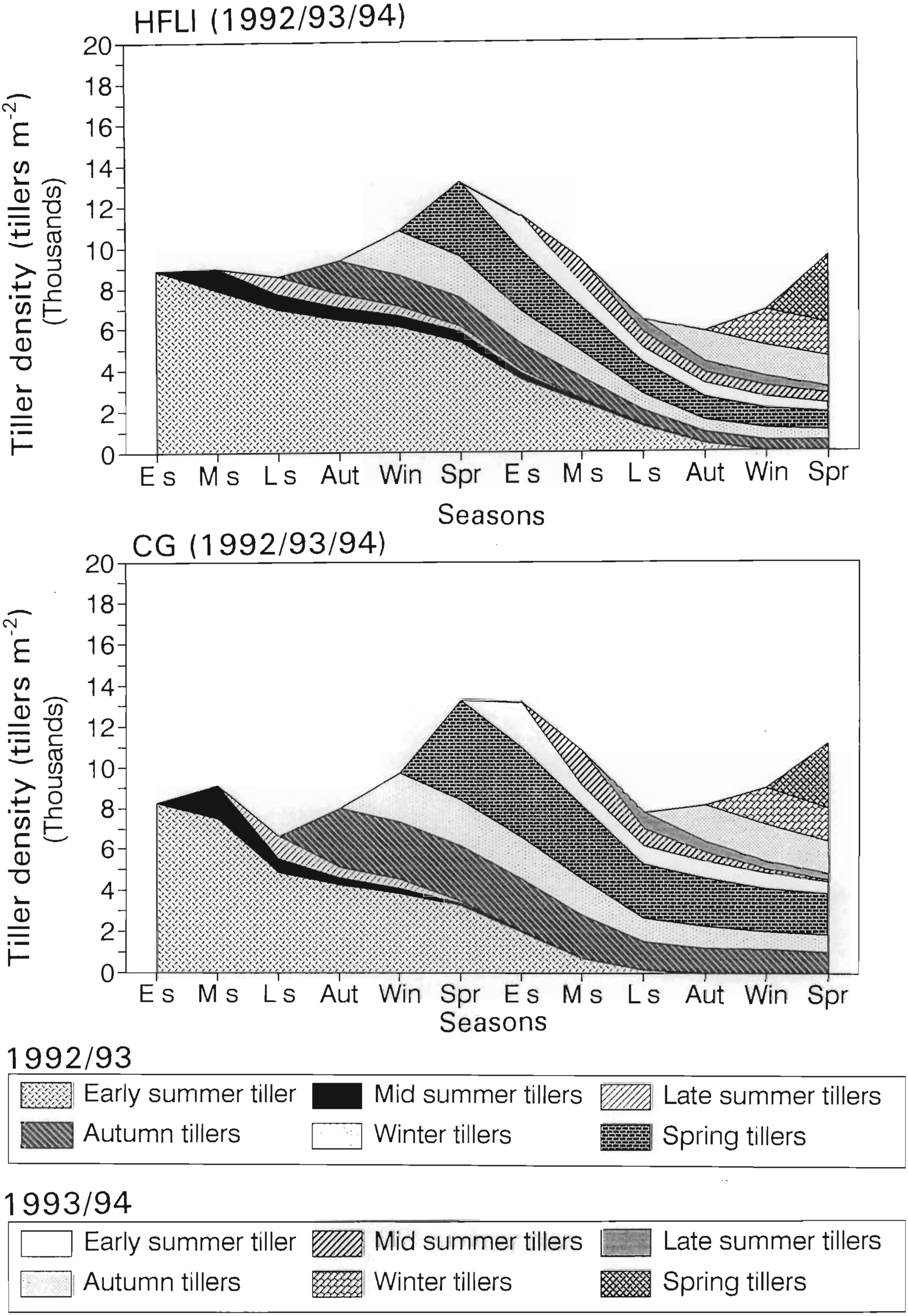


Figure 3.3 The survival of tillers originating during



MFMI (1992/93/94)
Tiller density (tillers m-2)
(Thousands)
0
2
4
6
8
10
12
14
16
18
20
E s
M s
L s
Aut
Win
Spr
E s
M s
L s
Aut
Win
Spr
Seasons
LFLI (1992/93/94)
Tiller density (tillers m-2)
(Thousands)
0
2
4
6
8
10
12
14
16
18
20
E s
M s
L s
Aut
Win
Spr
E s
M s
L s
Aut
Win
Spr
Seasons
1992/93
Early summer tiller
Mid summer tillers
Late summer tillers
Autumn tillers
Winter tillers
Spring tillers
1993/94
Early summer tiller
Mid summer tillers
Late summer tillers
Autumn tillers
Winter tillers
Spring tillers



HFLI (1992/93/94)
Tiller density (tillers m-2)
(Thousands)
0
2
4
6
8
10
12
14
16
18
20
Es
Ms
Ls
Aut
Win
Spr
Es
Ms
Ls
Aut
Win
Spr
Seasons
CG (1992/93/94)
Tiller density (tillers m-2)
(Thousands)
0
2
4
6
8
10
12
14
16
18
20
Es
Ms
Ls
Aut
Win
Spr
Es
Ms
Ls
Aut
Win
Spr
Seasons
1992/93
Early summer tiller
Mid summer tillers
Late summer tillers
Autumn tillers
Winter tillers
Spring tillers
1993/94
Early summer tiller
Mid summer tillers
Late summer tillers
Autumn tillers
Winter tillers
Spring tillers

In addition, swards frequently and intensively grazed are also placed under stress. During vegetative growth, infrequent defoliation increases tiller longevity (Korte *et al.* 1985). These researchers concluded that under conditions of favourable moisture and nutrient availability, total tiller density is affected minimally by defoliation frequency, despite effects on tiller appearance and longevity. Results from this trial suggest that even when the nutrient and moisture supplies are adequate under sub-tropical conditions, tiller densities decline during summer, presumably due to stressful hot temperatures (Cooper & Tainton 1968; Vogel *et al.* 1978). Tiller survival during summer can, however, be enhanced by adopting a low grazing defoliation frequency (Table 3.9 & Figure 3.3). In support of this, Fulkerson *et al.* (1993) found that tiller survival was enhanced more by a low defoliation frequency (cut every 4 weeks) during summer than by a high defoliation frequency (cut every 2 weeks) under sub-tropical conditions in Australia.

On the other hand, Hunt and Brougham (1967) reported that very frequent, but lenient defoliation can have detrimental effects on plant development and survival over the summer in New Zealand. In such grazing systems it becomes necessary to allow a hard autumn 'clean up' grazing to reduce accumulated dead matter and sheath material to enhance tiller development and survival. Survival of tillers in the HFLI treatment of this trial, however, was good relative to other treatments (e.g. HFHI and CG) over the summer periods (Table 3.9 & Figure 3.3). On the other hand, survival of tillers in the LFHI treatment was also good relative to the HFHI and CG treatments over the summer periods. These results indicate that under sub-tropical conditions, a combination of both high grazing frequency and intensity (HFHI) is more detrimental to tiller survival during summer than either high grazing frequency and low intensity (HFLI) or low grazing frequency and high intensity (LFHI).

The survival potential of tillers originating in autumn, winter and spring was good relative to tillers originating in summer (Table 3.9 & Figure 3.3). This was generally the case for all treatments. However, those treatments frequently and intensively defoliated (HFHI and CG) had significantly lower ($P \leq 0.05$) survival potentials than the LFHI, MFMI, LFLI and HFLI treatments (Table 3.9). It has been observed elsewhere that tillers formed during spring are unlikely to survive the summer periods and most tend to die while still vegetative, while tillers formed after flowering survive to produce inflorescence the following summer (Langer 1956; Hill & Watkin 1975). This, however, was not found to be the case in this trial. Generally, for all treatments (but to a lesser extent for the HFHI and CG treatments), tillers originating during spring demonstrated good survival. These results show that tillers arising in autumn, winter and spring are all important in maintaining perenniality, while those originating during the summer periods exhibit poor survival. This is further supported when considering the proportions of tillers making up total populations in summer (Figure 3.3); these consisted mostly of autumn, winter and spring tillers. In addition, the overall survival of tillers originating in any season can, in most instances, be enhanced by decreasing the defoliation frequency, particularly during summer.

An exception to these trends was the reduced survival ($P \leq 0.05$) in the LFLI treatment in early summer 1993/94 of tillers originating the previous year (early summer 1992/93) (Table 3.9 & Figure 3.3). Possible reasons for this are examined in section 3.3.4.4.

3.3.4.4 Aerial and reproductive tillering

Perennial ryegrass reproductive and aerial tiller densities (square-root transformed) are presented in Tables 3.10 and 3.11, respectively. The untransformed treatment means of these are illustrated in Figure 3.4.

Table 3.10 The effect of grazing defoliation on reproductive tiller population densities, calculated for seasonal periods. Data are square-root transformed and LSD's (P=0.05) are presented. Observation periods when no reproductive tillers were encountered are represented by the asterisk (*)

	Treatments[1]						
Seasonal period	LFHI	HFHI	MFMI (tillers m^{-2})	LFLI	HFLI	CG	LSD (P=0.05)
Early summer (Oct/Nov 1992)	*	*	*	*	*	*	-
Mid summer (Dec/Jan 1992/93)	*	*	*	*	*	*	-
Late summer (Feb/Mar 1993)	*	*	*	*	*	*	-
Autumn (Apr/May 1993)	*	*	*	*	*	*	-
Winter (Jun/Jul 1993)	9.49	7.07	6.71	10.04	4.69	*	3.93
Spring (Aug/Sep 1993)	38.79	24.49	22.36	46.90	22.11	8.31	9.19
Early summer (Oct/Nov 1993)	34.97	23.45	36.95	49.78	30.17	11.75	8.25
Mid summer (Dec/Jan 1993/94)	12.45	7.09	27.89	34.25	11.09	*	7.23
Late summer (Feb/Mar 1994)	*	*	6.95	19.23	*	*	4.82
Autumn (Apr/May 1994)	*	*	*	*	*	*	-
Winter (Jun/Jul 1994)	10.81	5.19	8.48	10.72	6.71	5.11	3.45
Spring (Aug/Sep 1994)	27.80	15.46	18.28	33.84	9.21	9.17	10.36

[1]see footnote to Table 3.5

Table 3.11 The effect of grazing defoliation on aerial tiller population densities, calculated for seasonal periods. Data are square-root transformed and LSD's (P=0.05) are presented. Observation periods when no aerial tillers were encountered are represented by the asterisk (*)

Seasonal period	LFHI	HFHI	MFMI (tillers m^{-2})	LFLI	HFLI	CG	LSD (P=0.05)
	Treatments[1]						
Early summer (Oct/Nov 1992)	*	*	*	*	*	*	-
Mid summer (Dec/Jan 1992/93)	*	*	*	*	*	*	-
Late summer (Feb/Mar 1993)	10.30	*	8.25	12.21	6.10	*	5.94
Autumn (Apr/May 1993)	18.89	9.90	15.10	32.23	13.49	3.46	8.63
Winter (Jun/Jul 1993)	10.04	6.57	18.81	24.82	8.66	3.74	19.21
Spring (Aug/Sep 1993)	26.55	9.33	19.31	50.60	9.49	*	12.34
Early summer (Oct/Nov 1993)	17.23	6.03	18.03	24.49	7.21	6.24	11.35
Mid summer (Dec/Jan 1993/94)	5.09	*	3.97	19.21	*	*	4.23
Late summer (Feb/Mar 1994)	*	*	*	*	*	*	-
Autumn (Apr/May 1994)	13.49	8.43	9.75	32.36	15.97	6.48	8.95
Winter (Jun/Jul 1994)	20.62	5.09	19.16	23.85	9.22	3.87	11.34
Spring (Aug/Sep 1994)	30.30	9.17	24.96	47.15	8.43	4.13	8.13

[1]see footnote to Table 3.5

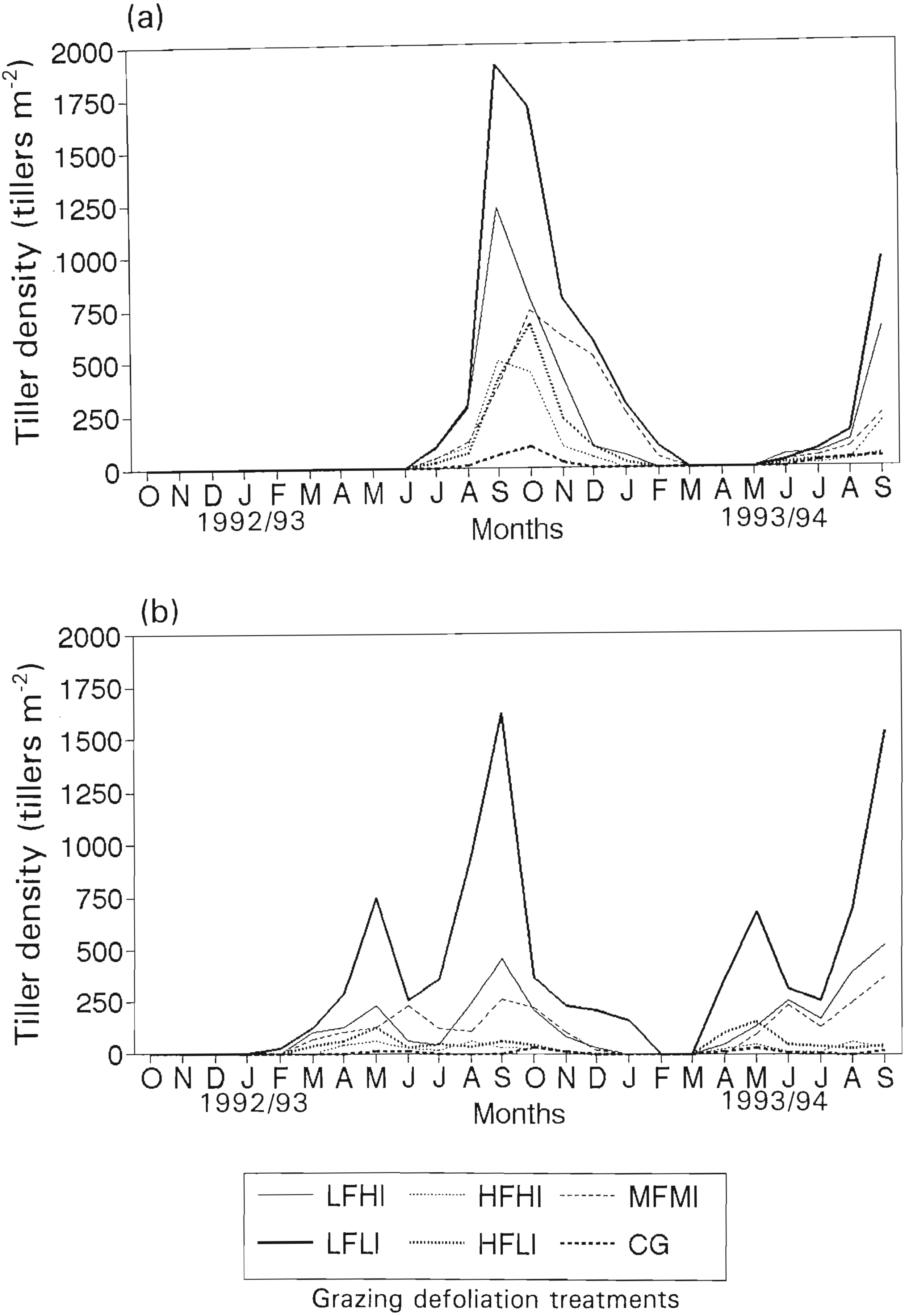


Figure 3.4 Perennial ryegrass (a) reproductive and (b) aerial tiller densities for the two year period.

Reproductive tillers contributed to total sward tiller density from late winter to mid summer and in some cases (MFMI and LFLI treatments) to late summer (Table 3.10 & Figure 3.4(a)).

There was no indication of reproductive tiller formation from early summer to autumn of 1992/93 and again during autumn of 1993/94 (Table 3.10 & Figure 3.4(a)). The main period of reproductive tiller initiation was from August to October. This is approximately two months earlier than in perennial ryegrass pastures in New Zealand (Korte *et al.* 1984; Korte 1986; L'Huillier 1987). Korte (1986) suggested that differences in temperature and day-length associated with latitude can cause reproductive initiation to be delayed. For the sub-tropical conditions of South Africa, both increasing day-length and temperature after winter occurs earlier than for New Zealand (D.C.W. Goodenough 1994, personal communication, Roodeplaat Grassland Institute, Private Bag X9059, Pietermaritzburg, 3 200, South Africa).

Generally, the LFLI and, to a lesser extent, the LFHI treatments had higher ($P \leq 0.05$) reproductive tiller densities than the HFHI and CG treatments (Table 3.10). For the LFLI treatment, reproductive tiller density ranged from 102 (July 1993) to 1900 (September 1993) tillers m^{-2} and from 29 (June 1994) to 980 (September 1994) tillers m^{-2} (Figure 3.4(a)). In comparison, the CG treatment had the lowest reproductive tiller density, ranging from 13 (August 1993) to 100 (October 1993) tillers m^{-2} and from 25 (July 1994) to 46 (September 1994) tillers m^{-2}. Similar results were obtained by L'Huillier (1987), where low stocking rates on perennial ryegrass resulted in higher reproductive tiller densities than high stocking rates. Soper (1958) found that on completion of flowering, a number of vegetative tillers associated with the reproductive tillers also died. In addition, Soper (1958) found that swards with fewer flowering tillers exhibited better survival of vegetative tillers. This has been recorded on other occasions under temperate conditions (Langer 1972; Colvill & Marshall 1984). This observation may be linked to the increased TDR noted for the LFLI treatment during early summer (Table 3.7).

Records (not presented) of tagged tillers showed that vegetative tillers originating in early summer and autumn of the 1992/93 year became reproductive in spring 1993/94. Hill and Watkin (1975) showed a similar pattern of development in New Zealand. Korte (1986) demonstrated that very few vegetative tillers originating in winter became reproductive during the following spring. Instead, vegetative tillers originating in spring and early summer became reproductive the following spring. On becoming reproductive, however, such tillers no longer contribute to sward persistence. Thom (1991) demonstrated that reproductive tillers had a higher overall probability of dying than vegetative tillers, regardless of the defoliation treatment.

Aerial tillers contributed to total sward tiller density from late summer (1992/93) to early summer (1993/94) and in some cases (LFHI, MFMI and LFLI treatments) to mid summer (Table 3.11 & Figure 3.4(b)). No aerial tillers were observed from early summer to mid summer (1992/93) and again during late summer (1993/94) (Table 3.11 & Figure 3.4(b)). This is perhaps due to summer-related heat stress limiting tillering in general (Table 3.6) and also the associated high TDR (Table 3.7) at these times. Even if aerial tillers had been initiated at these times, they may have not have survived long enough to be recorded. Ong (1978) shows that smaller, weaker tillers (which often include aerial tillers) are the first to succumb during stress.

Grazing treatments significantly influenced the number of aerial tillers (Table 3.11). The LFLI and, to a lesser extent, the LFHI treatments had higher (often significantly, $P \leq 0.05$) aerial tiller densities than the HFHI and CG treatments (Table 3.11). For the

LFLI treatment, aerial tiller density ranged from 25 (February 1993) to 1620 (September 1993) tillers m^{-2} and from 362 (August 1994) to 1524 (September 1994) tillers m^{-2} (Figure 3.4(b)). In contrast, the CG treatment had the lowest aerial tiller density, ranging from 123 (May 1993) to 14 (June 1993) tillers m^{-2} and from 5 (July 1994) to 29 (May 1994) tillers m^{-2}. Other treatments incorporating high to moderate defoliation frequency and/or high to moderate levels of defoliation intensity (e.g. MFMI and HFLI) also had lower aerial tiller densities than the LFLI treatment for all observations, although not necessarily significantly so (P>0.05) (Table 3.11). These results reflect the work of other researchers who have shown high aerial tiller densities for leniently grazed swards relative to intensively grazed swards (Tainton 1974; Korte *et al.* 1987; L'Huillier 1987). Greater shading of vegetative tillers probably occurred in the LFLI treatment and this condition has often been shown to promote aerial tillering (Hughes & Jackson 1974; L'Huillier 1987).

While aerial tillers where found in all the treatments studied, their contribution to total tiller densities was relatively minor, even for the LFLI treatment. The highest aerial tiller density for the LFLI treatment was 2 570 tillers m^{-2} during the spring of 1993 (August and September) (Figure 3.4(b)), while for the same period the total tiller density was 12 554 tillers m^{-2} (Table 3.5). Aerial tillers thus represented only 20% of the total tiller population for an extreme case. In a study by Korte *et al.* (1987), the most leniently defoliated treatment developed aerial tillers to a maximum of 10% of the total tiller population. Overall, it is not believed that aerial tillers contribute to the persistence of perennial ryegrass. Records (not presented) generally showed that aerial tillers usually died in the one month period between markings or were removed by grazing. Korte *et al.* (1987) found that aerial tillers did not root effectively and a high proportion were removed during grazing.

3.3.5 Conclusions

Total perennial ryegrass tiller densities declined during the summer periods and increased during the autumn, winter and spring periods. Seasonal fluctuations in total tiller density were lowest for those treatments infrequently defoliated (i.e. LFHI and LFLI). This suggests that low rather than medium to high defoliation frequencies impart a greater stability to total perennial ryegrass tiller densities under sub-tropical conditions. Intensive defoliation did produce the highest tiller densities, but only when coupled with a low level of defoliation frequency (i.e. LFHI).

There was a tillering 'flush' from autumn to spring, relative to the summer periods. This 'flush' was highest for spring, with a minor trough in winter and was associated with a high TAR and low TDR for these periods. Conversely, during the summer periods the TAR were low while the TDR were high. These tillering 'flushes' from autumn to spring are considered important because they resulted in an almost doubling of the tiller densities after the late summer period for most treatments.

Seasonal patterns of tillering and death are largely unaffected by defoliation treatments. However, both TAR and TDR can be manipulated within a given season by defoliation. High frequency and intensity defoliations initially produced high TAR, but these were lower after one and a half years relative to other treatments. On the other hand, high frequency and intensity defoliations consistently produced the highest TDR relative to other treatments. Generally, for the sub-tropical conditions experienced during the trial, the LFLI and LFHI treatments proved to be the most stable (in terms of tiller survival), particularly during the summer periods. Overall, however, perennial ryegrass swards are more stable (in terms of tiller survival) during the cooler (autumn, winter and spring) than the warmer seasons (early to late summer).

The survival of tillers originating during summer was poor in all treatments, but was enhanced by adopting a low grazing defoliation frequency (LFHI and LFLI). Conversely, the survival of tillers originating in autumn, winter and spring was better relative to tillers originating in summer. This was generally the case for all treatments. However, those both frequently and intensively defoliated (HFHI and CG) had lower survival potentials than those less frequently and/or less intensively (LFHI, MFMI, LFLI and HFLI) defoliated. Overall, results showed that tillers arising in autumn, winter and spring are all important in maintaining perenniality, while those originating during the summer periods are not.

The main period of reproductive tiller initiation was from August to October. This is approximately two months earlier than for perennial ryegrass pastures in New Zealand. Generally, the LFLI, and, to a lesser extent, the LFHI treatments had higher reproductive tiller densities than the HFHI and CG treatments.

The LFLI and, to a lesser extent, the LFHI treatments had higher aerial tiller densities than the HFHI and CG treatments. Overall, it is not believed that aerial tillers contribute to the persistence of perennial ryegrass.

3.4 Herbage production and quality

3.4.1 Introduction

There are no reliable data describing the effects of varying defoliation frequencies and intensities on perennial ryegrass DM production and quality under sub-tropical conditions. While such parameters (yield and quality) are often characterized for cutting trials (Fulkerson & Michell 1987; Perennial ryegrass evaluation pamphlets, 1984 - 1994, Roodeplaat Grassland Institute, Private Bag X9059, Pietermaritzburg, 3 200, South Africa), the study reported in this section was specifically designed to gain information on the effects of different grazing defoliation frequencies and intensities on DM production and quality. Also, there is relatively little information on seasonal herbage DM production patterns and seasonal quality patterns (Goodenough *et al.* 1991), and this was seen as an opportunity to gain an understanding of these.

3.4.2 Sampling procedure

Herbage DM production was estimated using the pasture disc meter (Bransby & Tainton 1977). This is essentially an indirect measure of herbage DM (kg ha^{-1}) and calibration is necessary with this technique when quantification is desired. Calibration employs a double-sampling technique in which indirect readings are associated with actual DM readings obtained by direct sampling; the relation between the two (regression equation) is used as the basis for predicting direct values (Frame 1981). Unfortunately, indirect estimates have greater error and are more liable to bias than direct methods (Meijs *et al.* 1982). The error problem with indirect sampling can be offset by increasing numbers of readings per unit area while bias can be reduced by frequent calibration (Burns *et al.* 1989). In this regard then, 50 disc meter readings were taken per plot at any sampling period. In addition, the pasture disc meter was re-calibrated at the start of each season (i.e. four times per year) and separately for each treatment (i.e. six grazing treatments). This was deemed necessary to limit any bias in estimating DM production which may have arisen due to an altered sward structure developing in response to a particular grazing treatment. Herbage DM production was thus an estimate of the DM consumed by the sheep and was calculated from the yield estimate (disc meter regression) just before sheep entered a camp, minus the herbage remaining when animals left the camp.

For the duration of the trial, six randomly placed quadrats (25 cm X 25 cm) per plot were clipped prior to each grazing period. From the bulked sample of these, a sub-sample was taken, dried in a forced draught oven at 60 °C for 48 hours, milled and stored in a deep freeze until subsequent quality analyses could be conducted. Herbage separations were carried out on bulked samples to apportion total yield among perennial ryegrass and other 'weed' species (see section 3.6; Table 3.15 for a breakdown of 'weed' species).

The *in vitro* digestibility of herbage samples was estimated from cellulase DM disappearance (CDMD), using the cellulase digestion procedure (Zacharias 1986). Herbage N was estimated using an auto-analyzer incorporating a technique based on a modification of the Kjeldahl method (Hambleton 1977). Both CDMD and herbage N were estimated for the total sward composition, and not for perennial ryegrass and weed species individually. In line with addressing persistency related parameters, characterising changes in total sward quality was deemed more appropriate than separating perennial ryegrass and weed species.

3.4.3 Data analysis

Herbage DM production and quality data were analyzed using analysis of variance (randomized blocks design) (Steel & Torrie 1981). Because the number of sampling observations were not equal for treatments (i.e. sampling dictated by grazing frequency) 'Duncan's multiple range' tests rather than LSD tests were applied to treatment means (Rayner 1967). Seasonal data were smoothed by high order polynomial regressions (Steel & Torrie 1981). The 'goodness of fit' between the original and predicted (smoothed) data was described by the correlation between these.

3.4.4 Results and discussion

3.4.4.1 Dry matter production

Total herbage DM yields, perennial ryegrass DM yields and DM yields of weed species on a seasonal basis are presented in Tables 3.12 and 3.13 (1992/93 and 1993/94, respectively). Patterns of perennial ryegrass DM accumulation and weed DM accumulation for the entire experimental period are presented in Figure 3.5, and the contribution of perennial ryegrass to total yield appears in Figure 3.6.

Total DM production ranged from 15 663 (CG) to 18 815 (LFHI) kg ha^{-1} in the first year (Table 3.12), and from 9 924 (CG) to 18 085 (LFLI) in the second year (Table 3.13). Treatments incorporating a low level of defoliation frequency (LFHI and LFLI) significantly ($P \leq 0.05$) out-yielded those with higher defoliation frequencies (HFHI, MFMI and CG) in the first year, with the exception of HFLI. Interestingly, DM production declined in all treatments during the second year (Table 3.13) relative to the first year (Table 3.12). This decline, however, was markedly less for those treatments incorporating low defoliation frequencies (LFHI and LFLI) than those incorporating higher defoliation frequencies (HFHI, HFLI, MFMI and CG). No statistical differences ($P > 0.05$) between the LFHI and LFLI treatments were observed for total (full year) perennial ryegrass

Table 3.12 Total herbage, perennial ryegrass and weed species DM production (estimated yield removed by sheep) on a seasonal and annual basis (1 October 1992 to 30 September 1993). Treatment means with letters in common are not significantly different ($P \leq 0.05$)

Season		Treatments[1] LFHI	HFHI	MFMI (kg ha^{-1})	LFLI	HFLI	CG
Early	Total	1338 a	1207 a	969 b	990 b	1001 ab	1035 ab
Summer	Ryegrass	1311 a	1185 a	943 b	985 b	963 ab	1012 ab
(Oct/Nov)	Weeds	27 a	22 a	26 a	5 a	38 a	23 a
Mid	Total	2633 ab	2416 b	2282 bc	2937 a	2553 ab	2013 bc
Summer	Ryegrass	2488 ab	2304 b	2160 bc	2912 a	2408 ab	1849 c
(Dec/Jan)	Weeds	145 a	112 a	122 a	28 b	146 a	164 a
Late	Total	3342 a	2651 b	3889 a	2668 b	3121 a	3355 a
Summer	Ryegrass	3028 a	2455 b	3598 a	2549 b	2891 b	3152 a
(Feb/Mar)	Weeds	314 a	196 b	292 ab	120 b	230 ab	203 ab
Autumn	Total	5279 a	3651 b	4051 b	4930 a	4784 a	3573 b
(Apr/May)	Ryegrass	5157 a	3493 b	3858 b	4858 a	4662 a	3370 b
	Weeds	122 ab	158 a	193 a	73 b	122 ab	203 a
Winter	Total	2666 a	2367 a	2652 a	2962 a	2838 a	2645 a
(Jun/Jul)	Ryegrass	2660 a	2351 a	2635 a	2954 a	2818 a	2620 a
	Weeds	6 a	16 a	17 a	8 a	20 a	25 a
Spring	Total	3557 b	3534 bc	4048 ab	4173 a	3882 ab	3042 c
(Aug/Sep)	Ryegrass	3550 b	3500 bc	4031 ab	4166 a	3859 ab	2981 c
	Weeds	7 a	34 a	17 a	6 a	23 a	61 a
Totals	Total	18815 a	15826 b	17891 a	18660 a	18179 a	15663 b
(year)	Ryegrass	18194 a	15288 b	17225 a	18424 a	17601 a	14884 b
	Weeds	621 a	538 ab	666 a	236 b	578 ab	779 a

[1]see footnote to Table 3.5

Table 3.13 Total herbage, perennial ryegrass and weed species DM production (estimated yield removed by sheep) on a seasonal and annual basis (1 October 1993 to 30 September 1994). Treatment means with letters in common are not significantly different ($P \leq 0.05$)

Season		LFHI	HFHI	MFMI	LFLI	HFLI	CG
		Treatments[1] (kg ha^{-1})					
Early	Total	4113 b	3043 c	3636 bc	4918 a	3111 c	3019 c
Summer	Ryegrass	4087 b	2936 c	3600 bc	4865 a	2917 c	2725 c
(Oct/Nov)	Weeds	26 c	107 c	36 c	53 c	194 b	294 a
Mid	Total	2942 a	1830 b	2737 a	2815 a	1772 b	1565 b
Summer	Ryegrass	2708 a	1404 b	2265 a	2687 a	1396 b	1003 b
(Dec/Jan)	Weeds	234 bc	426 ab	472 ab	128 c	376 b	562 a
Late	Total	1439 a	1154 a	1147 a	1582 a	1429 a	1056 a
Summer	Ryegrass	1216 a	684 b	733 b	1313 a	1008 a	636 b
(Feb/Mar)	Weeds	223 b	470 a	414 a	269 b	421 a	420 a
Autumn	Total	2256 b	1785 c	2352 b	4091 a	2456 b	1659 c
(Apr/May)	Ryegrass	2047 b	1376 c	1952 b	3834 a	2063 b	1295 c
	Weeds	209 b	409 a	400 a	257 b	393 a	364 a
Winter	Total	2070 a	1154 b	1230 b	1337 b	1270 b	984 b
(Jun/Jul)	Ryegrass	2008 a	937 bc	1153 bc	1288 b	1145 bc	754 c
	Weeds	62 b	217 a	77 b	49 b	125 ab	231 a
Spring	Total	3164 ab	1841 c	2863 b	3342 a	2461 b	1641 c
(Aug/Sep)	Ryegrass	3135 ab	1614 c	2737 b	3318 a	2361 b	1470 c
	Weeds	29 c	227 a	126 bc	24 c	100 bc	171 ab
Totals	Total	15984 a	10807 c	13965 b	18085 a	12499 b	9924 c
(year)	Ryegrass	15201 a	8737 c	12440 b	17305 a	10890 b	7883 c
	Weeds	783 c	2070 ab	1525 b	780 c	1609 b	2041 ab

[1]see footnote to Table 3.5

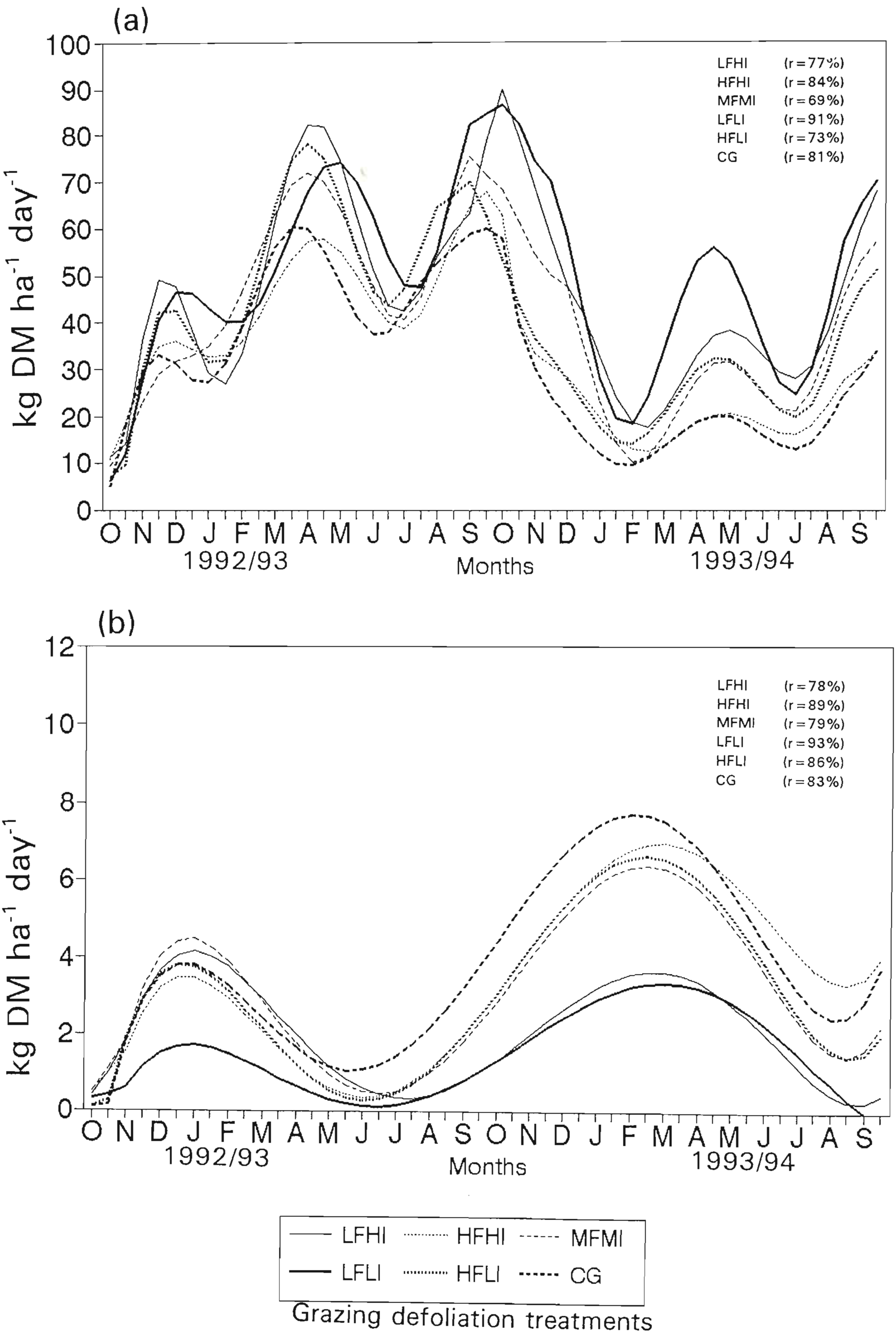


Figure 3.5 Patterns (smoothed) of (a) perennial ryegrass, and (b) weed herbage DM accumulation rates for the entire experimental period. The 'goodness of fit' between smoothed and original data was

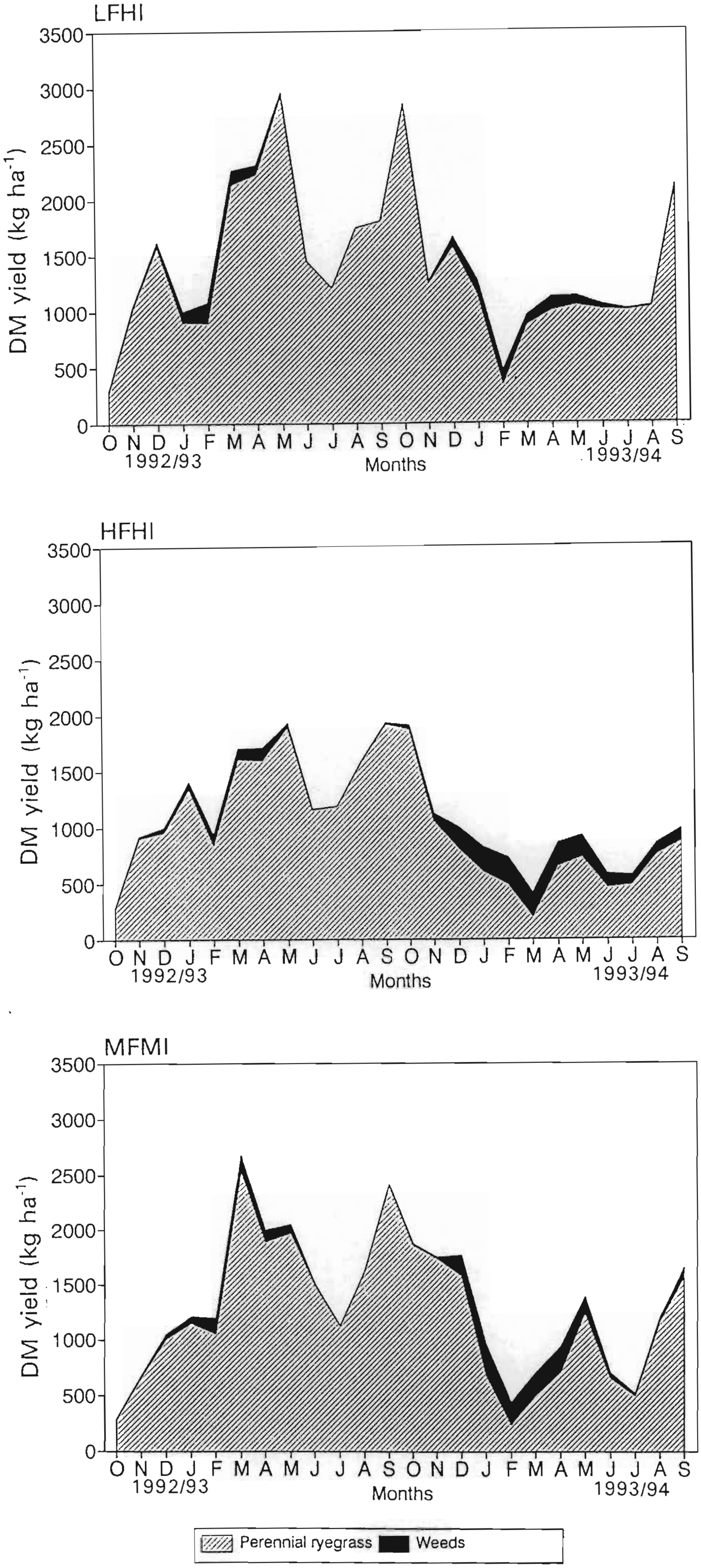
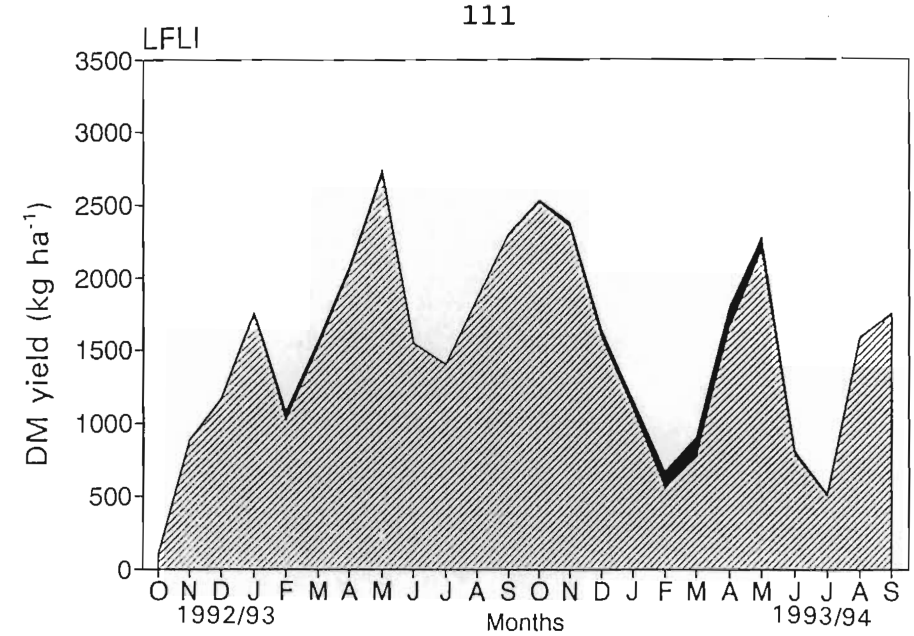
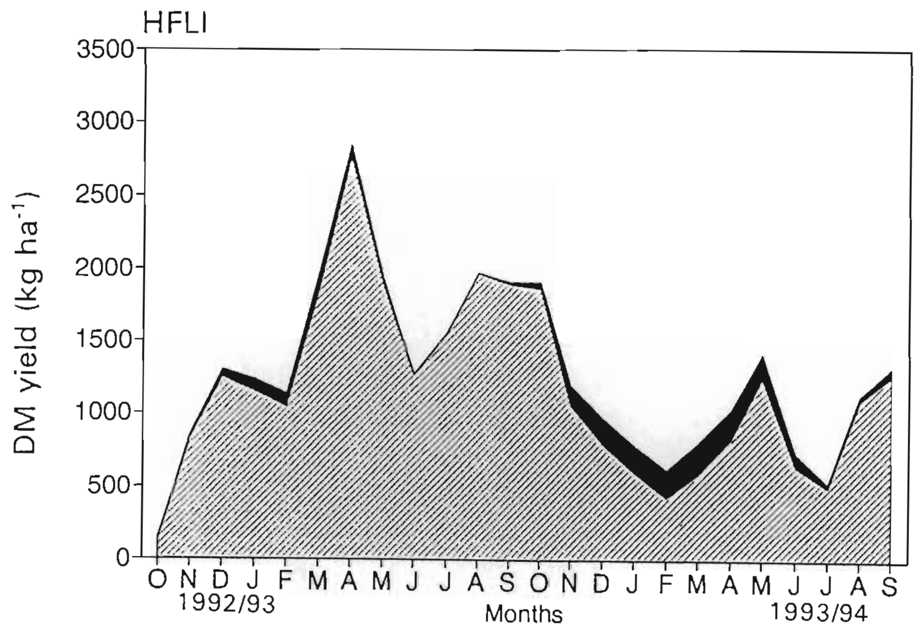


Figure 3.6 The effect of grazing management on seasonal species composition of a perennial ryegrass pasture (1 October 1992 to 30 September 1994).





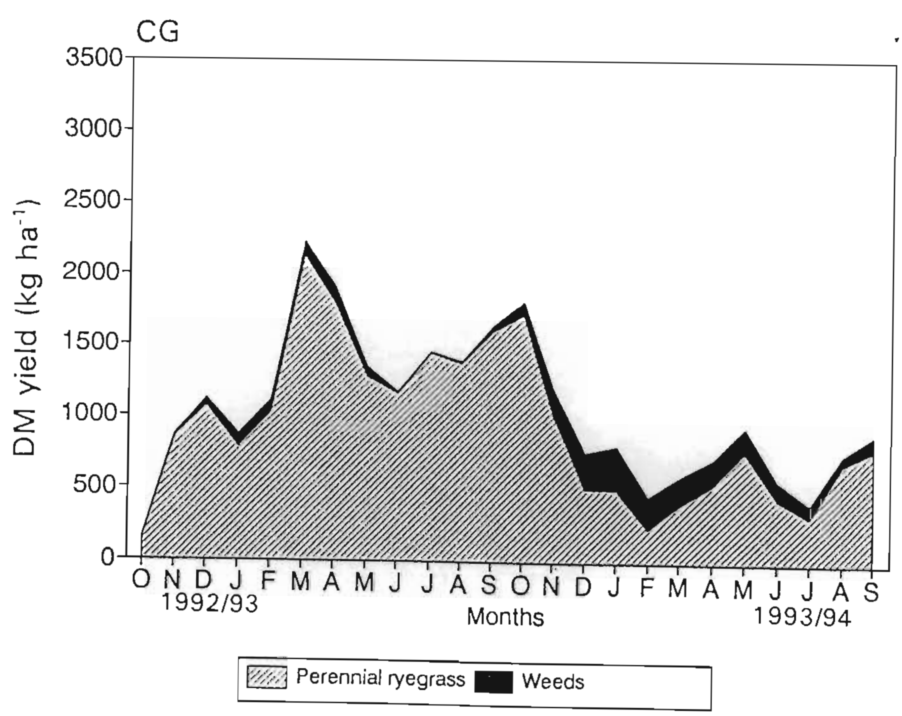


Figure 3.6 continued

DM production during both years. These data show that defoliation intensity is relatively less important in influencing herbage DM production than defoliation frequency.

Brougham (1959) reported that for perennial ryegrass, annual DM yields were highest under grazing regimes incorporating periods of long rest. Yields were also high under frequent, but lenient grazing, and markedly less where grazing intensity was severe. Subsequent research on perennial ryegrass under temperate conditions has substantiated these findings. Generally, more frequent and more intense defoliations reduce herbage yield (Holliday & Wilman 1965; Harris 1978; Motazendian & Sharrow 1986), while infrequent and lenient defoliations increase herbage yield (Tainton 1974; Lambert *et al.* 1986; Lowe & Bowdler 1988; Togamura *et al.* 1993).

The proportion of weed species contributing to total DM production also increased markedly during the second year, particularly during mid summer, late summer and autumn for treatments incorporating high defoliation frequencies (HFHI, MFMI, HFLI and CG), relative to those incorporating low defoliation frequencies (LFHI and LFLI) (Figure 3.6). This was particularly well illustrated during the second year in the HFHI and CG treatments in which perennial ryegrass production was relatively low ($P \leq 0.05$) (Figure 3.6 & Table 3.13). These lower levels of perennial ryegrass DM production in treatments incorporating high defoliation frequencies (e.g. HFHI, CG and HFLI, particularly in year two) may be due to reduced vigour of perennial ryegrass under such management. This is investigated in section 3.5. In addition, these treatments (e.g. HFHI and CG) also exhibited a high proportion of weed DM production relative to treatments incorporating low defoliation frequencies (e.g. LFHI and LFLI), particularly during the summer months of year two. Fulkerson *et al.* (1993) also reported lower DM yields for a perennial ryegrass pasture under sub-tropical conditions during its second year as a result of weed invasion.

All treatments demonstrated relatively high perennial ryegrass DM production during the autumn and spring periods, with low levels of DM production during the mid to late summer and the winter periods for both years (Tables 3.12 & 3.13). Such patterns of DM production over time, with high levels occurring during spring (August and September) and autumn (April and May), and low levels occurring during mid to late summer (January and February) and winter (June and July) are illustrated in Figure 3.5. The pattern shows a similar trend for all treatments, the only differences being between treatments within any given season. Generally, DM accumulation over time was higher for treatments incorporating low defoliation frequencies (LFHI and LFLI) than those incorporating higher defoliation frequencies (HFHI, MFMI, HFLI and CG) (Figure 3.5). It must be cautioned, however, that such patterns of DM accumulation may indeed differ for other areas in South Africa. The seasonal DM yields for perennial ryegrass pastures in New Zealand are not consistent for different areas in New Zealand. For example, Stevens and Hickey (1989) reported highest DM yields during spring and lowest during winter, and Barker *et al*. (1993) also reported highest DM yields during spring, but lowest during autumn. By way of contrast, Moloney *et al*. (1993) found DM yields to be highest during summer, and lowest during winter. It would appear that seasonal yields in New Zealand are primarily a function of both effective rainfall distribution and favourable temperatures during different seasons.

Production of weeds also followed a typical pattern with highest rates of DM accumulation occurring during mid to late summer (January and February) (Figures 3.5 & 3.6). Such a trend can be expected since these weed species (e.g. *Digitaria sanguinalis, Eleusine indica, Eragrostis curvula, Sporobolus africanus*, etc.) are tropical and their growth is most active during this period of the year (Gibbs Russell *et al.* 1990). This trend increased dramatically during the second year in most treatments (HFHI, MFMI, HFLI and CG), but to a lesser extent in treatments incorporating low defoliation frequencies (LFHI and LFLI) (Figures 3.5 & 3.6). These results show that low grazing defoliation frequencies, rather than low grazing intensities, suppress weed production during the second year after establishment. Thus, adopting such a grazing programme (incorporating low frequencies) should help address the problem of weed invasion reported by many perennial ryegrass farmers in KwaZulu-Natal (CHAPTER 2, section 2.6.7).

3.4.4.2 Herbage quality

The CDMD values for the total sward composition are given in Figure 3.7 (1992/93 and 1993/94), while herbage N values for the total sward composition are given in Figure 3.8 (1992/93 and 1993/94). Patterns of herbage CDMD and herbage N for the entire experimental period are presented in Figure 3.9.

The total sward CDMD digestibility ranged from 55% in autumn (MFMI) to 77% during early summer (CG) in the first year. During the second year, CDMD ranged from 49% in late summer (HFLI) to 70% in spring (LFLI) (Figure 3.7). Interestingly, the general level of CDMD dropped by approximately 7% for all treatments during the second year relative to the first year (Figure 3.7). This may be attributed to the higher proportion of weed species contributing to total sward production in the second year (see section 3.4.4.1). These results compare favourably with other published data. Generally, *in vitro* digestibility of perennial ryegrass under temperate conditions is in the range of 65 to 80% (Morton *et al.* 1992; Barker *et al.* 1993; Stevens & Turner 1993).

While treatment differences were relatively small, the LFLI treatment exhibited lower CDMD digestibility ($P \leq 0.05$) than most

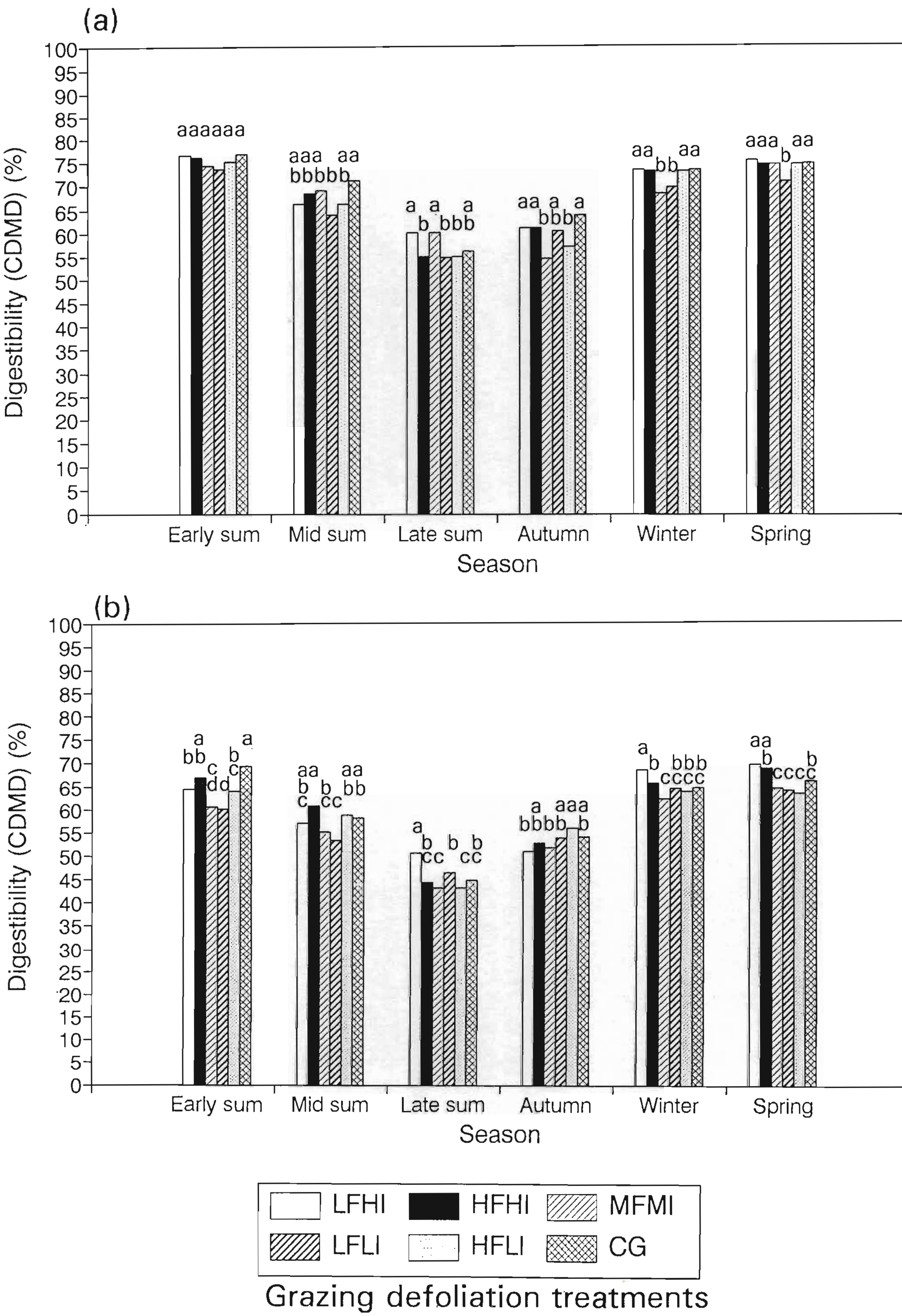


Figure 3.7 Total sward herbage digestibility (CDMD) on a seasonal basis (a) 1 October 1992 to 30 September 1993 and (b) 1 October 1993 to 30 September 1994.

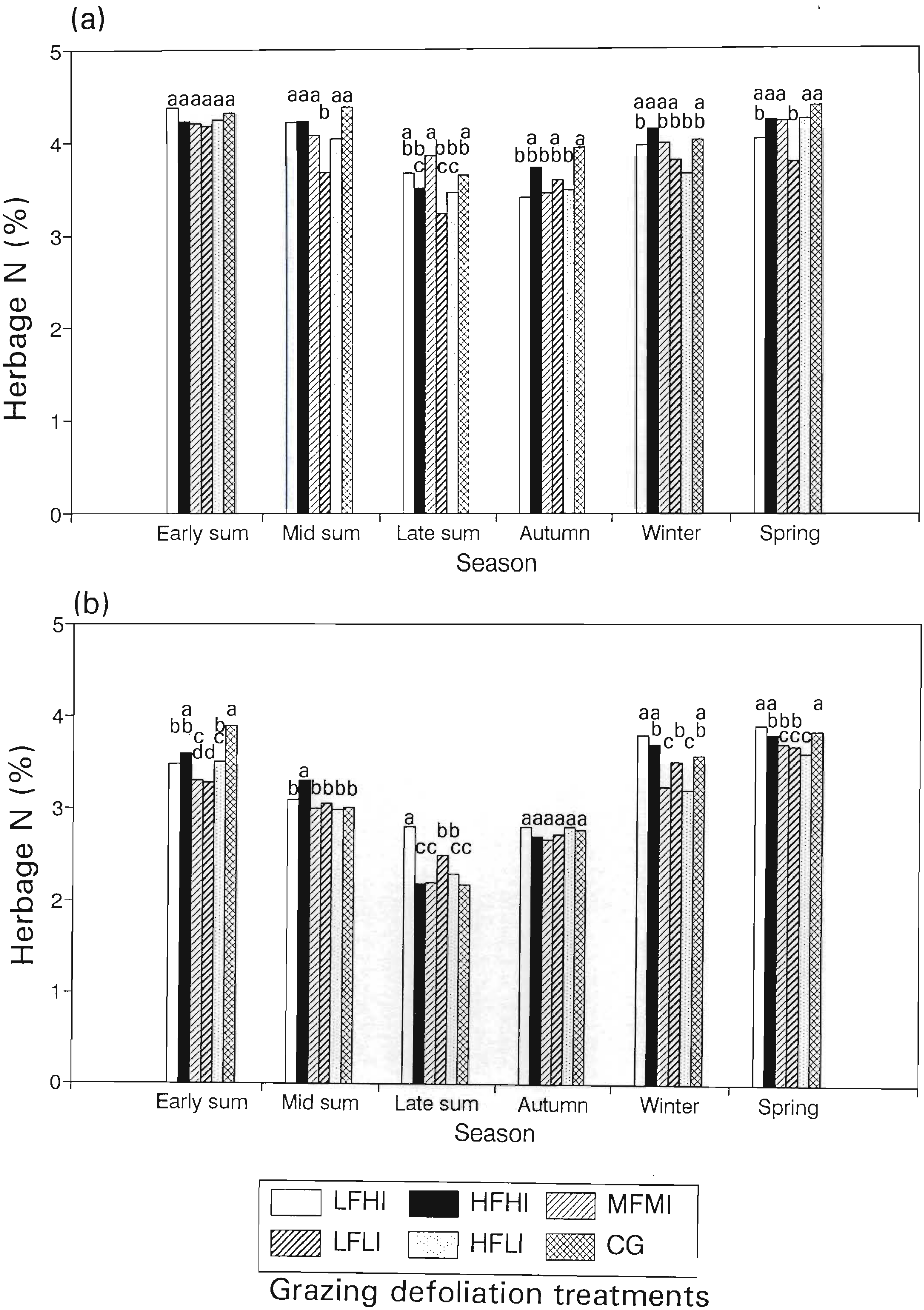


Figure 3.8 Total sward herbage N on a seasonal basis (a) 1 October 1992 to 30 September 1993 and (b) 1 October 1993 to 30 September 1994. Bars with

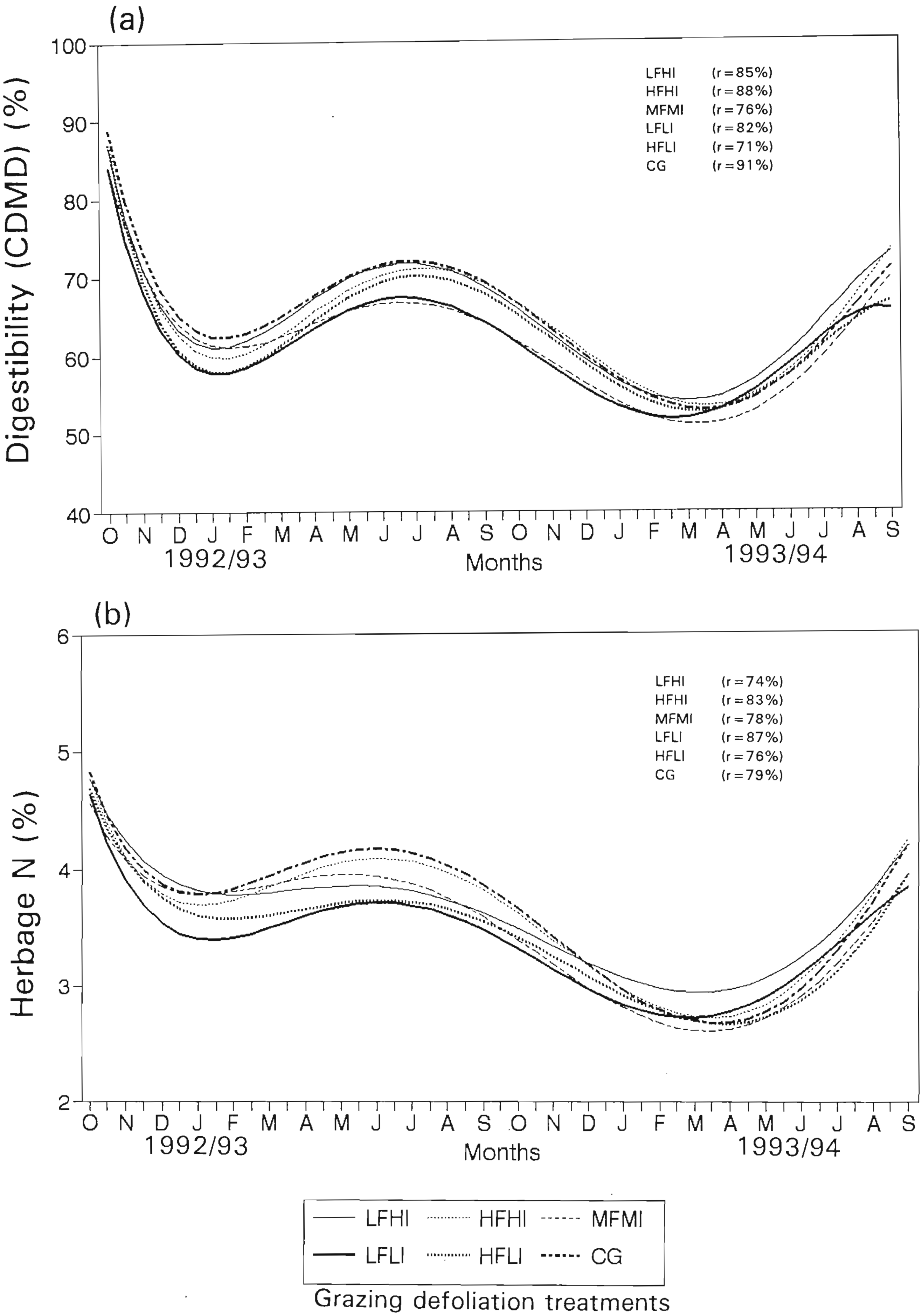


Figure 3.9 Patterns (smoothed) of (a) total herbage CDMD, and (b) total herbage N for the entire experimental period. The 'goodness of fit' between smoothed and original data was estimated

of the treatments incorporating higher levels of defoliation frequency and intensity (LFHI, HFHI, MFMI, HFLI and CG) in all seasons, except early summer, during year one (Figure 3.7). This has been observed for perennial ryegrass under temperate conditions where low cutting frequency depresses herbage digestibility (Frame 1987). During the second year, the LFHI and HFHI treatments performed well in most of the seasons (except during autumn) relative to many of the other treatments.

Total sward herbage N was observed to range from 3.2% in late summer (LFLI) to 4.4% in mid summer and spring (CG) in the first year. During the second year, herbage N ranged from 2.1% in late summer (CG) to 3.9% in spring (LFHI) (Figure 3.8). The general level of herbage N dropped during the second year relative to the first year by approximately 0.7% (Figure 3.8). This may also be attributed to the higher proportion of weed species (tropical grasses) contributing to total sward production in the second year (see section 3.4.4.1). Tropical species usually exhibit lower herbage quality than temperate species (Bredon & Stewart 1978). These levels of herbage N also compare well with published data. Generally, herbage N values for well managed perennial ryegrass pastures under temperate conditions range from 2.2 to 4.2% on a DM basis (Baker & Leaver 1986).

While treatment differences were again relatively small during the first year, the LFLI treatment generally exhibited lower levels of herbage N than the other treatments in most seasons (except during autumn and winter), many of these being significant ($P \leq 0.05$) (Figure 3.8). During the second year, the LFHI treatment performed relatively well, except during early and mid summer.

A similar seasonal pattern of CDMD and herbage N was observed for all treatments and during both years (Figure 3.9). This pattern was characterised by having high levels of CDMD and herbage N during the late autumn to early summer period (May to October) and low levels during the mid summer to early autumn period (January to April). The seasonal pattern of *in vitro* digestibility of perennial ryegrass has been found to range from a low of 66% in summer, 70% in autumn, 77% in spring and to a high of 78% in winter (Barker *et al.* 1993).

One explanation for these trends may be that all treatments were relatively leniently defoliated during the summer months, which may have contributed to a build-up of low quality residual material during this time. Conversely, all treatments were defoliated relatively more severely during autumn, and even more so during winter, which may help explain the improvement in general herbage quality at these times. Herbage digestibility has been found to decrease as the proportion of dead material in the sward increases (Togamura *et al.* 1993). The proportion of dead material above ground increases throughout the season, being more marked in grazed than in cut swards (Jones *et al.* 1982). Advancing maturity has also been associated with declining herbage N and digestibility (Ashford & Troelsen 1965). Chestnutt *et al.* (1977) reported a reduction in digestibility of perennial ryegrass when defoliation frequency by cutting was increased from two to eight weeks.

3.4.5 Conclusions

From a DM production view, there is little justification for employing frequent defoliation. Low defoliation frequencies (e.g. 21, 28 and 35 days during summer, spring/autumn and winter, respectively) allowed for superior yields of perennial ryegrass during both years under sub-tropical conditions at Ukulinga, relative to high defoliation frequencies (e.g. 7, 14 and 21 days during summer, spring/autumn and winter, respectively). In addition, high frequency grazing tends to promote a higher level of weed production, particularly during the second year, relative to low frequency defoliation treatments. Interestingly, grazing defoliation intensity did not appear to influence DM production.

The seasonal DM production trend for perennial ryegrass at Ukulinga was characterized by high levels during spring and autumn, and low levels during mid to late summer and winter.

While the LFLI treatment tended to exhibit lower CDMD and herbage N levels than the other treatments, these differences were generally small. Overall, these levels of herbage digestibility and N fall within similar ranges for perennial ryegrass under temperate environments.

The seasonal trend in quality for perennial ryegrass pastures at Ukulinga (for both CDMD and herbage N) was characterized by high levels during late autumn to early summer (May to October) and low levels during mid to early autumn (January to April).

3.5 Perennial ryegrass vigour

3.5.1 Introduction

In cultivated pastures, the greatest vigour and productivity occur when the majority of tillers making up the sward are relatively young. This can be achieved either by ploughing up and resowing a pasture, or by adopting management practices which result in tiller survival and the replacement of older tillers by vigourous young tillers (Mitchell & Glenday 1958). Since the broad objective of the trial was to seek ways of enhancing the survival of perennial ryegrass without re-establishment, the latter of these alternatives formed the basis of this investigation.

It is believed that the vigour of perennial ryegrass, particularly during the summer months when the threat of invasion by tropical grass species is greatest, plays an important role towards determining its potential to survive. In this regard, reserve carbohydrates within the plant are of interest, especially when the supply of carbon from actively photosynthesizing leaves is periodically interrupted by grazing. It has been shown that defoliation at increasingly frequent intervals tends to deplete carbohydrate reserves progressively and results in decreased growth and sometimes death of plants (Steinke & Booysen 1968; Thom *et al*. 1986; Daphne 1992). Carbohydrate reserves also tend to become increasingly depleted as the intensity of defoliation increases (Grant *et al*. 1981).

The objective of this study was, therefore, to measure the effects of both grazing frequency and grazing intensity on perennial ryegrass vigour, and identify which grazing treatment/s will best enhance the vigour of perennial ryegrass within a particular season.

To achieve this objective, etiolated growth was used to provide an index of vigour. Edwards (1965) showed that both vigour and regrowth of grass plants in the dark was related to the level of carbohydrate reserves and that etiolated growth provided an index of these reserves.

3.5.2 Sampling procedure

Etiolated growth was measured under light proof 'boxes'. These 'boxes' were designed to allow plants to grow in the total absence of light. The light proof 'boxes' (circular with 300 mm internal diameter) comprised double sides which allowed some air circulation and insulated the interior against excessively high temperatures. They were also painted black on the interior and silver on the exterior to assist in reducing excessive internal temperatures. These designs were based on the suggestions of Edwards (1965).

Two randomly located quadrats (20 cm X 20 cm) per plot were clipped using a pair of scissors. This, in effect, provided a total of eight observations per grazing treatment (2 quadrats X 4 treatment replications). Daphne (1992) found that six observations per treatment were adequate to explain treatment differences. These clipped areas were then watered (Muzzell & Booysen 1969) and light proof 'boxes' placed over them.

Areas within each quadrat were carefully defoliated in such a way that only lamina were removed. In addition, where grass tufts extended beyond the boundaries of the quadrat, these too were defoliated in an attempt to prevent any possible translocation of reserve carbohydrates from un-clipped to clipped sections of the same tuft. Only short vegetative stem material and leaf sheath material remained after clipping. In this way, almost all active photosynthesizing leaf material was removed and most growth apices presumably remained intact.

After clipping and placement of light proof 'boxes', etiolated growth was measured at two week intervals for up to four weeks after clipping (i.e. a total of two observation periods). Muzzell and Booysen (1969) demonstrated that etiolated growth in grasses could continue for several months, and that it took up to two weeks before treatment effects became obvious. In my study, however, etiolated growth tended to cease after two weeks. Retention of the light proof 'box' beyond this time often resulted in death of the entire clipped area below the 'box' and very little subsequent etiolated growth. This was again observed for sampling periods in mid (1992/93) and late summer (1992/93). For this reason, therefore, all subsequent sampling sessions lasted for two weeks only, and etiolated growth data which had been collected after the two week period for the first three sampling periods were discarded.

When sampling, the light proof 'box' was removed and the quadrat relocated with the aid of wire pins which marked its original position after initial clipping. Etiolated growth which had occurred within the boundaries of the relocated quadrat was then harvested. At this stage, the number of tillers contributing to etiolated growth was also estimated. Any contribution from tillers other than perennial ryegrass (i.e. weed species) was discarded as estimating the vigour of perennial ryegrass was the primary concern of the study.

Over the duration of the trial (two years) a total of twelve observations were made, each during the last month of a seasonal period, namely November, January, March, May, July and September. The objectives were thus to estimate perennial ryegrass vigour after a season of implementation of a particular grazing treatment, and to estimate the effect of season on etiolated growth.

3.5.3 Data analysis

For the etiolated growth measures, total dry weight per unit area and the number of contributing tillers were quantified at each sampling session. Data were summarized in two ways:

1) as dry weights of eight observations for each of the six treatments (i.e. an index of plant vigour). An analysis of variance (randomized blocks design incorporating nested sub-sampling) was conducted on logarithmically (natural logarithms) transformed data which were expressed per unit area. Least significance difference tests were applied to treatment means (Steel & Torrie 1981); and
2) as the extent to which mean cumulative dry weight per unit area was influenced by individual tiller performance (i.e. an index of individual tiller vigour). Tiller performance was indexed by the quotient of total tiller number (within a quadrat) and dry etiolated weight, i.e. average tiller weight. A square-root transformation was applied to the tiller data before subjecting these to analysis of variance (randomized blocks design incorporating nested sub-sampling). Least significance difference tests were applied to treatment means (Steel & Torrie 1981).

3.5.4 Results and discussion

Presented in Figures 3.10 and 3.11 are, for each treatment and expressed per unit area, the average total dry weights of etiolated growth which occurred over a two week period for six seasons in 1992/93 and 1993/94, respectively. These figures illustrate both transformed and untransformed treatment means.

Evident from the results was that no significant ($P>0.05$) treatment differences occurred between early summer and autumn during the '1992/93 establishment year (Figure 3.10). Lack of significance was perhaps due, in part, to treatment effects not yet expressing themselves. However, a definite trend began to

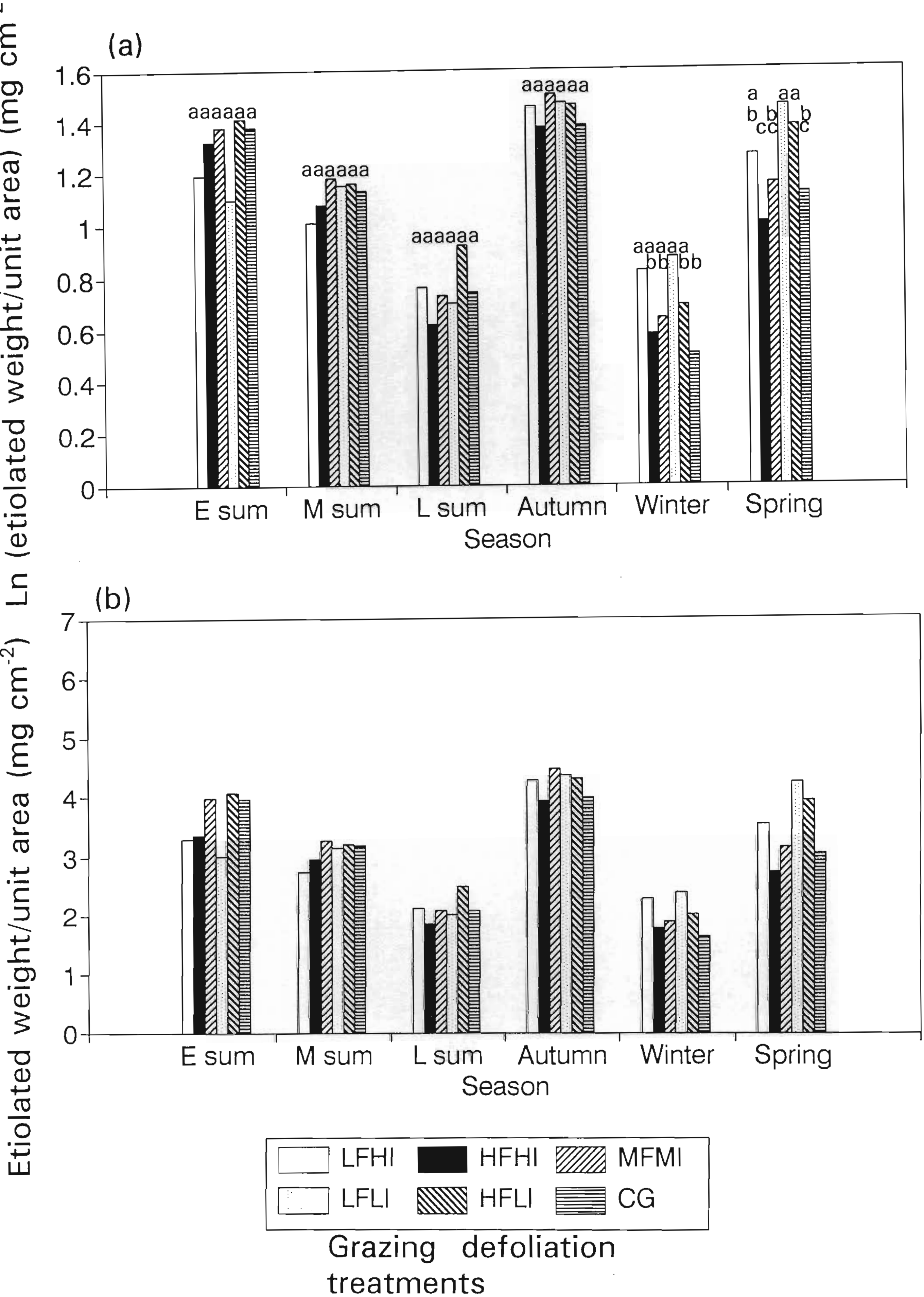


Figure 3.10 Average total etiolated dry weight per unit area (a) (natural log transformed; bars with letters in common are not significantly different (P>0.05)) and (b) (untransformed treatment means) produced by each treatment over a two week period

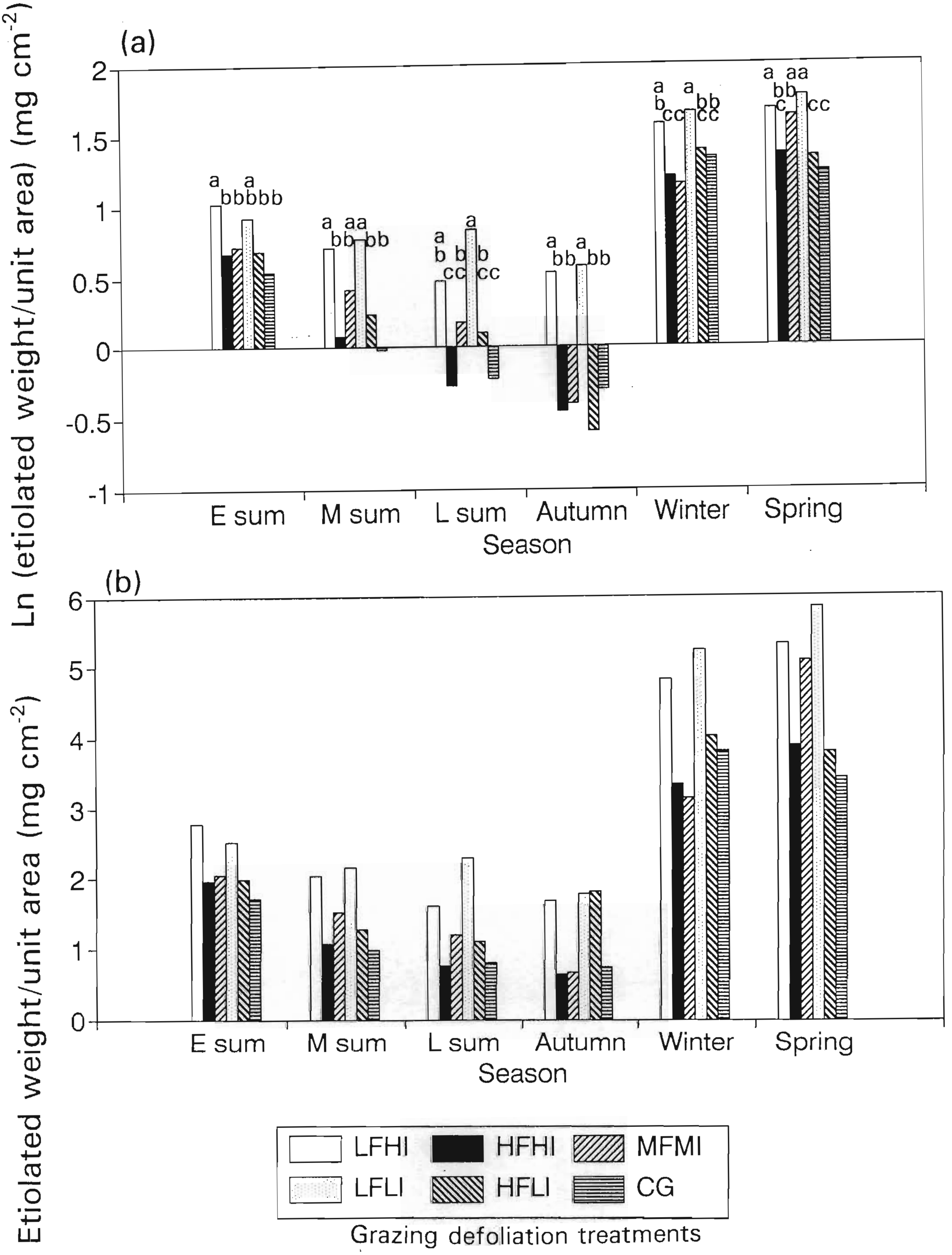


Figure 3.11 Average total etiolated dry weight per unit area (a) (natural log transformed; bars with letters in common are not significantly different (P>0.05)) and (b) (untransformed treatment means) produced by each treatment over a two week period

emerge during winter and spring of the 1992/93 year, where treatments infrequently defoliated (LFHI and LFLI) significantly ($P \leq 0.05$) out-yielded those that were more frequently defoliated (e.g. HFHI and CG). These results support earlier studies (e.g. Steinke & Booysen 1968; Grant *et al.* 1981; Thom *et al.* 1986; Hodgkinson *et al.* 1989; Daphne 1992) that have associated frequent defoliation with a reduction in carbohydrate reserves.

The trend that had manifested itself by winter of the 1993/94 year (Figure 3.10) continued throughout that year (Figure 3.11). The LFHI and LFLI treatments continued to significantly ($P \leq 0.05$) out-yield other treatments that were more frequently defoliated (including the MFMI treatment). No defoliation intensity effects were observed, which suggests that defoliation frequency is of greater importance in influencing carbohydrate reserves than defoliation intensity. Contrary to these results, Hughes and Jackson (1974) reported a decline in the persistency of perennial ryegrass when carbohydrate reserves were depleted and root growth reduced, as a result of intense grazing defoliation. Grant *et al.* (1981) stated that carbohydrate reserves declined rapidly after defoliation, the extent of the decline being related to the severity of the defoliation. The effective leaf area remaining after grazing influenced the extent to which carbohydrate reserves were depleted during the early stages of regrowth.

Regardless of treatment effect, there was a general decline in plant vigour over the late summer and winter periods during the 1992/93 year. This was well illustrated for both transformed and untransformed data (Figure 3.10). For the 1993/94 year, however, the summer (early to late summer) and autumn seasons produced relatively low plant vigour, perhaps due to the high summer temperatures (> 25 °C) encountered at the trial site (Table 3.2). Temperatures above 25 °C are known to reduce the growth potential of perennial ryegrass (Cooper & Tainton 1968; Vogel *et al.* 1978). Lower production levels from perennial ryegrass during summer have also been noted under temperate conditions in New Zealand. Some authors have observed that perennial ryegrass daughter tillers produced during autumn - early winter are initially small and contribute little to herbage growth. However, the contribution of such new tillers increases and by late winter makes up 60% of the total leaf growth (Korte *et al.* 1982; Fulkerson & Michell 1987). It appears, therefore, that pasture growth in late winter to spring depends on daughter tillers produced in autumn to early winter, and that stimulation of autumn tillering by removal of summer residues may increase subsequent pasture growth. Such a view was also supported by Hunt and Brougham (1967).

Also of note (from untransformed data in Figures 3.10 and 3.11) was that plant vigour, regardless of treatment, was generally lower during the 1993/94 year than the 1992/93 year for the summer (early to late) and autumn periods, but not for the winter and spring periods. This would suggest that the general vigour of perennial ryegrass declines more during the summer period of a second year than during the summer period of a first year under sub-tropical conditions. It appears that for perennial ryegrass, low vigour during summer is an inherent characteristic that is expressed under both temperate and tropical conditions.

Following on from expressing etiolated growth per unit area, was the need to examine if the frequently defoliated treatments produced low etiolated weights as a result of meristematic limitations (i.e. limited tiller initials) rather than the lack of available reserves. Daphne (1992) expressed such a sentiment by suggesting that frequently clipped plants may not have adequate lateral tiller growth points to utilise available reserves.

To examine this, the average etiolated dry weight for contributing tillers (i.e. the estimated number of tillers that

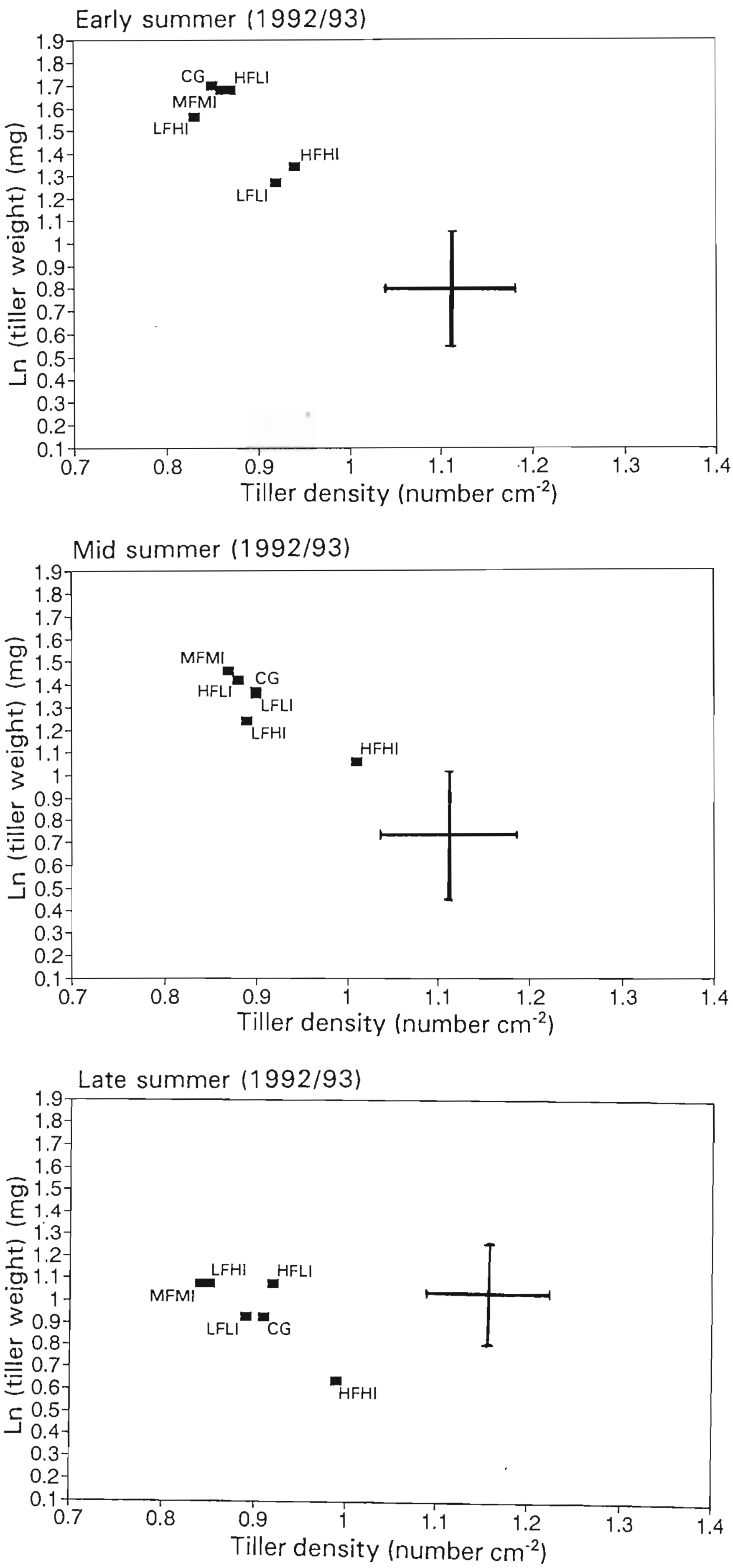
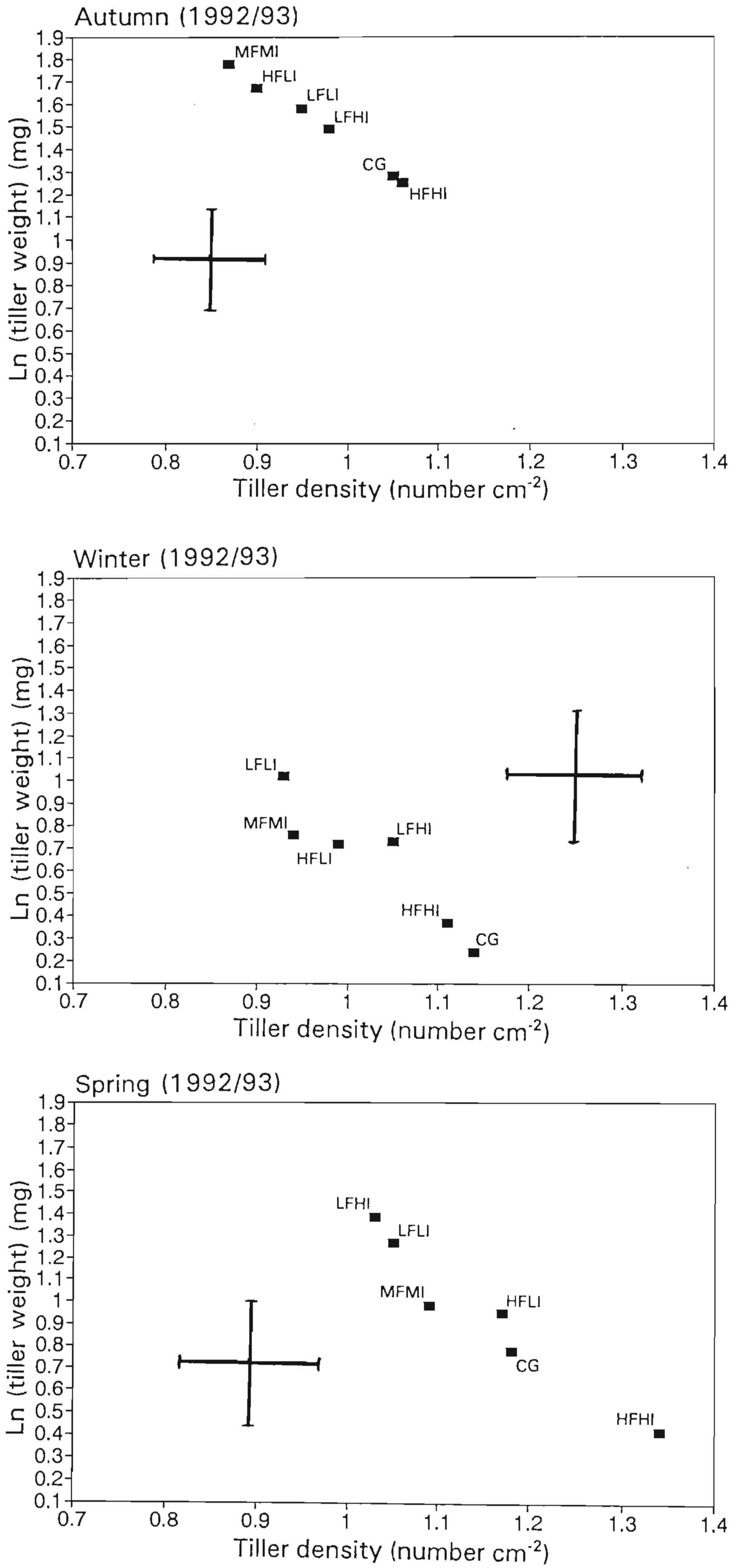


Figure 3.12 Average total etiolated tiller dry weight (natural log transformed) versus average tiller density (number per unit area and square-root transformed) for two weeks of regrowth and for six seasonal periods during 1992/93. The LSD (P=0.05) bars for each of weight and density are



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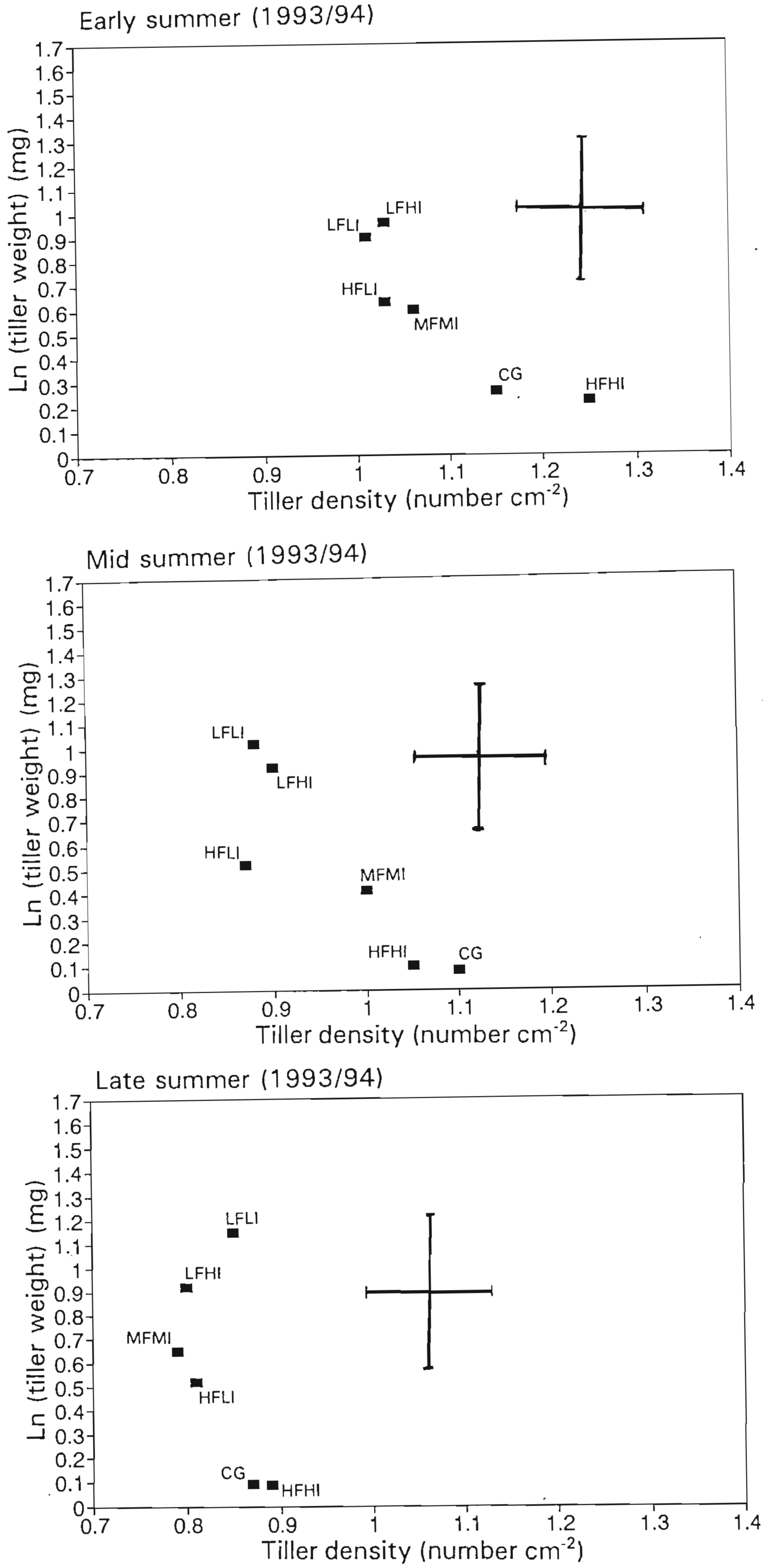


Figure 3.13 Average total etiolated tiller dry weight (natural log transformed) versus average tiller density (number per unit area and square-root transformed) for two weeks of regrowth and for six seasonal periods during 1993/94. The LSD

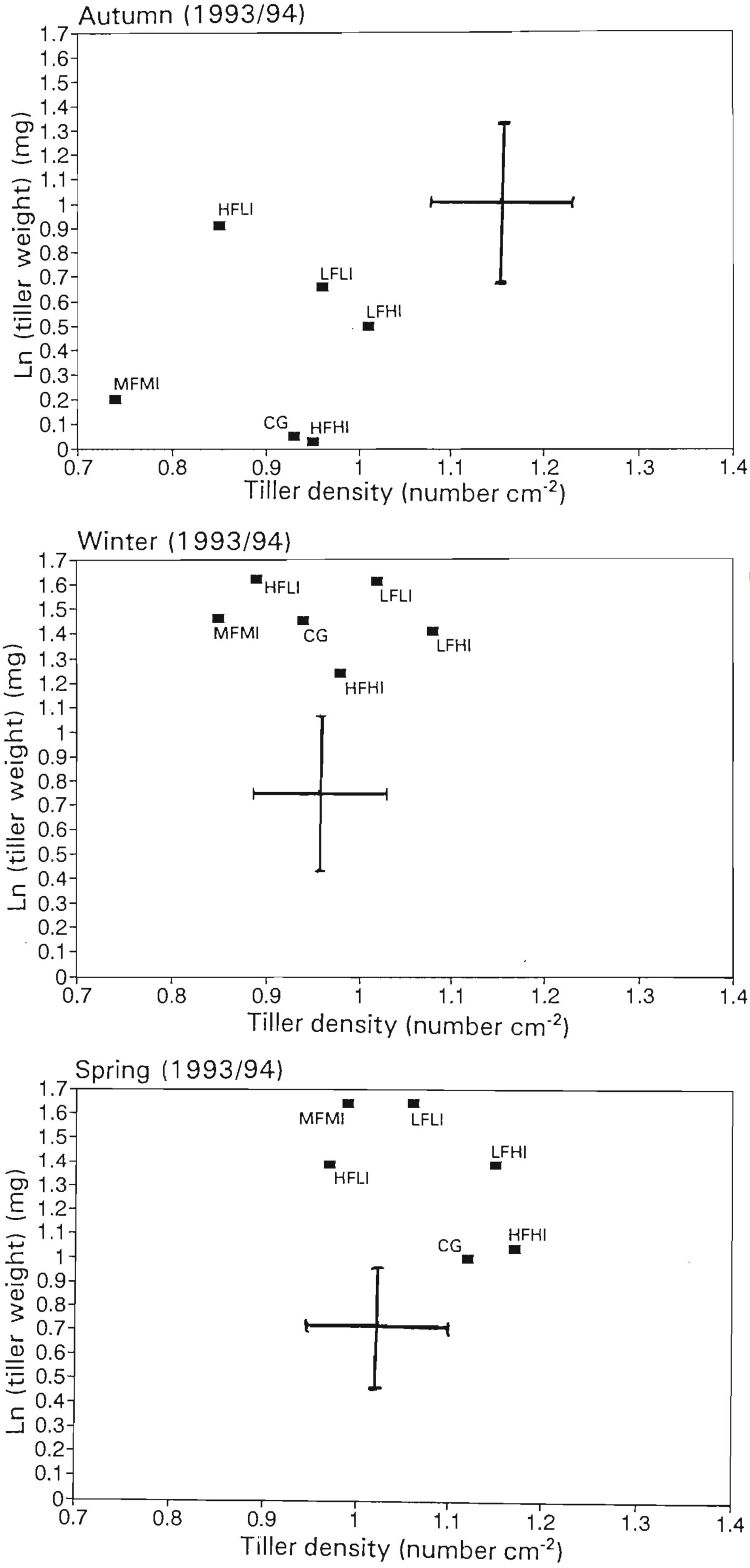


Figure 3.13 continued.

had contributed to etiolated growth) was plotted against an estimate of the average tiller density encountered within the quadrat. These results, for six periods of observation during 1992/93 and 1993/94, are presented in Figures 3.12 and 3.13.

During the first three observation periods of 1992/93 (early summer to late summer), no significant ($P>0.05$) treatment effects were evident (Figure 3.12). From the autumn period onwards, however, a distinct and significant ($P\leq0.05$) pattern emerged where treatments frequently and intensely defoliated (e.g. HFHI and CG) exhibited low average tiller weights and high tiller densities. This trend continued through to the spring period of this year (Figure 3.12). These results suggest that, for the first year, reduced etiolated growth in frequently and intensely defoliated perennial ryegrass was due to diminished carbohydrate reserves and not to a lack of active growth points to utilize these reserves. Parsons *et al.* (1984) found that continuous stocking on a pasture results in a sward comprising a large population of small tillers with consistently low rates of photosynthesis. It is noted, however, that regardless of the defoliation interval, animal grazing (particularly sheep) is selective and of variable intensity within a camp and this may lead to reduced persistence of grasses (Hughes & Jackson 1974).

Alternatively, tiller vigour reduction and death may also be influenced by the availability of light since prolonged shading causes death (Ong 1978). Due to selective grazing, under-utilized areas may result in both reduced viability and basal tiller bud development because of excessive shading (Langer 1972). This, however, was not observed in my study for the infrequently grazed treatments.

During the 1993/94 year (Figure 3.13) the trend observed towards the end of the 1992/93 year (where treatments frequently and intensively defoliated exhibited low average tiller weights and high tiller densities), continued for most of the observation periods (except during winter). In addition, the treatments which were infrequently defoliated (e.g. LFLI and LFHI) were consistently located at the opposite end of the graph to those frequently and intensely defoliated (e.g. HFHI and CG) in all seasons, except winter and spring (Figure 3.13). In most instances, these differences were significant ($P \leq 0.05$) for both tiller density and average tiller weight. Also of note is that for treatments frequently and intensely defoliated (HFHI and CG), the number of tillers contributing to etiolated growth declined. This became apparent from mid summer onwards for the 1993/94 year (Figure 3.13). These results suggest that during the second year, both reserve level and potential growth points became limiting factors for etiolated growth in frequently defoliated treatments. Conversely, tillers of those treatments infrequently defoliated (regardless of defoliation intensity level) appear to have greater relative vigour (as indexed by average tiller weights) than tillers from frequently defoliated treatments. It has been reported that plants grazed at short intervals over spring and summer are smaller and suffer more damage or die than plants grazed infrequently (Thom *et al.* 1986). Thom *et al.* (1986) also stated that larger plants are better able to survive both managerial and environmental stresses in summer. Larger plants are obtained under conditions of least stress, such as long grazing intervals and adequate irrigation during summer. A short grazing interval over late summer is found to be detrimental to ryegrass growth and survival. In this regard, Grant *et al.* (1981) concluded that production per tiller in intensively grazed swards is usually offset by a rapid increase in tiller numbers.

3.5.5 Conclusions

In terms of plant vigour (as indexed by etiolated growth per unit area), grazing defoliation treatments incorporating a low frequency (LFHI and LFLI) out-yielded those incorporating higher defoliation frequencies (HFHI and CG). This trend became apparent during the latter quarter (winter and spring) of the establishment year and continued throughout the second year. However, grazing defoliation intensity appeared to have no influence on plant vigour.

In terms of a seasonal trend, the vigour of perennial ryegrass (as indexed by etiolated growth per unit area) declined during mid to late summer of the establishment year and from early summer to autumn (inclusive) during the second year. It is also suggested (though inconclusively) that the overall vigour of perennial ryegrass may decline more in the summer period of the second year under sub-tropical conditions than the summer period of the establishment year.

For most of the trial period, the lack of etiolated growth in frequently defoliated treatments was apparently due mainly to poor growth reserves and not to a lack of active growth points. Towards the end of the second year, however, a lack of active growth points was also beginning to limit etiolated growth in the frequently defoliated treatments. Tillers from infrequently defoliated treatments (regardless of the level of grazing intensity) appeared to have greater vigour than tillers from the frequently defoliated treatments.

3.6 Weed invasion

3.6.1 Introduction

There tends to be a substantial decline in perennial ryegrass tiller populations and production during a summer period, and particularly during summer of the second year after establishment. This has been observed to be most pronounced in pastures frequently defoliated (section 3.3.3). It is generally not clear if such a condition is associated with the ingress of tropical (summer-growing) grasses such as *Digitaria sanguinalis, Eragrostis curvula, E. plana* and *Sporobolus africanus*.

The regeneration of perennial ryegrass tillers is important because this influences the ability of ryegrass plants to take advantage of niches created within the sward (e.g. niches created by treading damage, tiller death due to extreme temperature and species selection by the animal (Thom *et al.* 1986; Thom 1991)). During summer, however, ryegrass demonstrates a poor tillering ability (section 3.3.3) and by contrast, the tropical grass species (invaders) are highly active (Gibbs Russell *et al.* 1990). It is not surprising, therefore, that any niche created during summer has a greater chance of being occupied by tropical species than by perennial ryegrass. During summer, high frequency and high intensity defoliations tend to make more bare ground available for colonization by weed species (Weeda & During 1987).

Given these circumstances, any grazing management factors which substantially enhance the competitiveness of perennial ryegrass relative to potentially invasive tropical species over the summer months, should contribute to improving the longevity of these pastures.

Specific objectives of this study included estimating the tiller proportions of perennial ryegrass and weed species to the total sward tiller density; and estimating the relative frequencies of perennial ryegrass and weed species.

3.6.2 Sampling procedure

3.6.2.1 Destructive sampling

Initially, five randomly placed cores per plot (10 cm diameter: 78.54 cm^2) were harvested every second month. Justification for this sampling size is presented in the data of the pilot study conducted at Cedara Research Station (Figure 3.2, section 3.3.2). The material was moved to the laboratory for subsequent separation into perennial ryegrass and weed tillers which were then counted.

Similar approaches, using varying quadrat sizes and numbers have been adopted by numerous researchers (Table 3.14). However, since the contribution of weed tillers to total sward tillers was small, the sampling intensity was increased to ten quadrats per plot (i.e. 40 quadrats per treatment) to obtain more precise weed tiller density data.

Placement of cores was by means of a stratified random sampling approach (section 3.3.2).

Table 3.14 Some examples of studies that made use of destructive sampling to monitor perennial ryegrass tiller densities

Reference	Quadrat size	Number of quadrats per treatment
Brougham (1959)	5 cm diameter	35
Grant *et al.* (1981)	7.6 cm diameter	10
Bircham & Hodgson (1983)	10 X 5 cm	12
Cox *et al.* (1988)	11.85 cm diameter	8
King *et al.* (1988)	7.6 cm diameter	10

3.6.2.2. Non-destructive sampling

To identify the relative frequencies of weeds and perennial ryegrass making up the total sward, and to identify specific weed species and their relative frequencies, use was made of a non-destructive sampling technique. One hundred circular quadrats (10 cm diameter) were randomly placed per plot. The presence or absence of species occurring within these was recorded. This procedure was adopted during the last month of each seasonal period, namely: November, January, March, May, July and September during the second year of the trial. For each species group (i.e. perennial ryegrass and 'weeds'), data were expressed as the relative proportion (frequency) of the total number of plants encountered per plot.

3.6.3 Data analysis

Both tiller density (perennial ryegrass and weed species) and relative frequency data sets were subjected to analysis of variance (randomised blocks design incorporating nested sub-sampling). Least significance difference tests were applied to treatment means (Steel & Torrie 1981).

3.6.4 Results and discussion

A list of the grass species encountered in the perennial ryegrass pastures and an index of the relative occurrence of individual species is given in Table 3.15. Perennial ryegrass and weed tiller densities for six seasonal periods in 1992/93 and 1993/94 are presented in Figures 3.14 & 3.15. The relative frequency (%) of weed tiller density to total sward tiller density, also for six seasonal periods in 1992/93 and 1993/94, is given in Table 3.16. The relative frequencies of perennial ryegrass and weed species, also for six seasonal periods in 1993/94 are given in Figure 3.16, while the average relative frequencies for the six seasonal periods in 1993/94 are given in Figure 3.17.

Table 3.15 Grass species (weeds) encountered in the perennial ryegrass pastures and an index of their level of occurrence (1 = uncommon and 5 = very common). Broadleaved weeds and sedges were grouped into a forbes and sedges category

Species	Occurrence index
Cynodon dactylon	1
Digitaria sanguinalis	5
Echinochloa crusgalli	1
Eleusine indica	3
Eragrostis curvula	3
Eragrostis plana	1
Eragrostis tef	2
Panicum maximum	1
Paspalum distichum	2
Sporobolus africanus	1
Sedges	2
Forbs	3

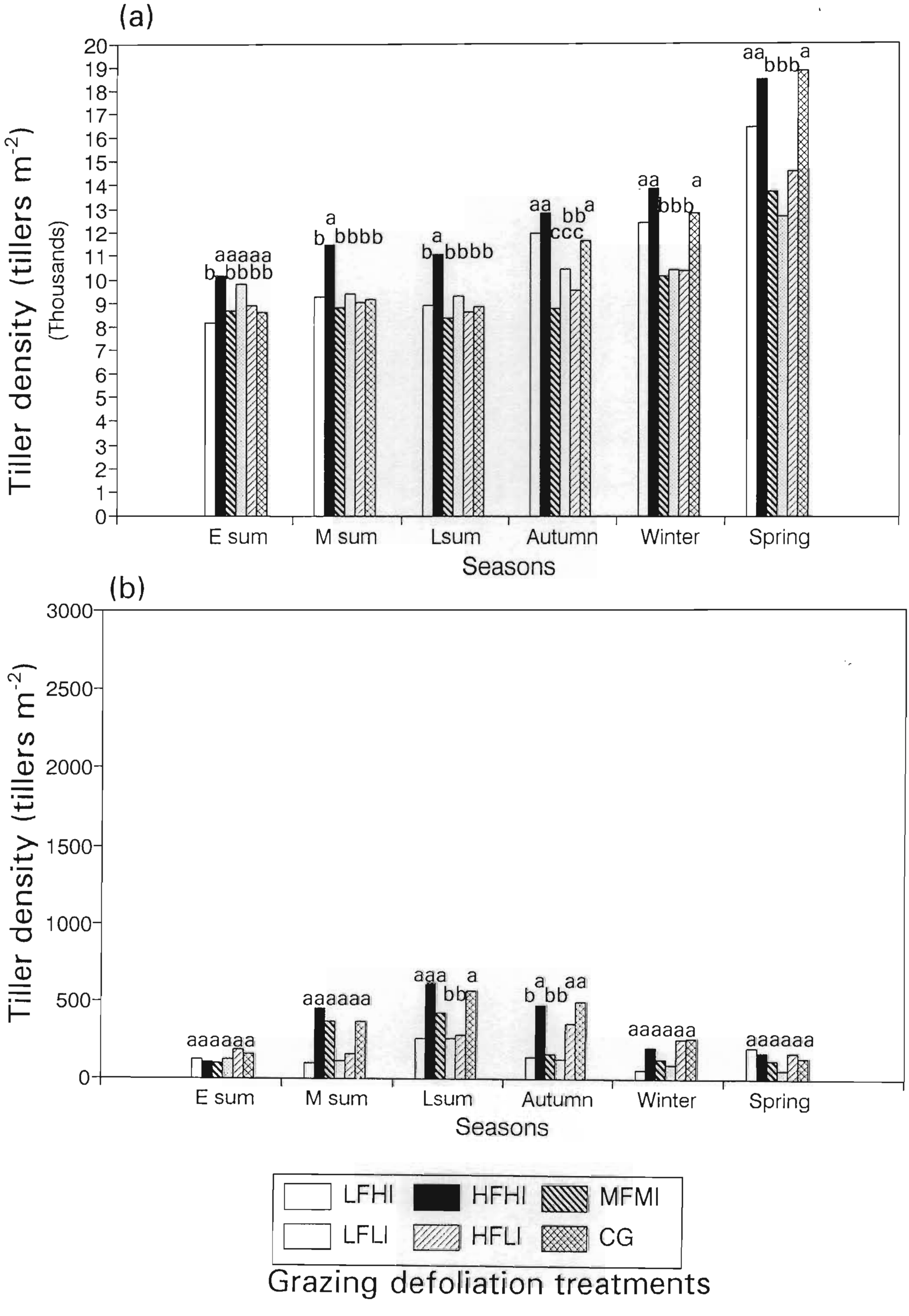


Figure 3.14 The effect of grazing defoliation on (a) perennial ryegrass tiller density, and (b) weed species tiller density during 1992/93. Bars with

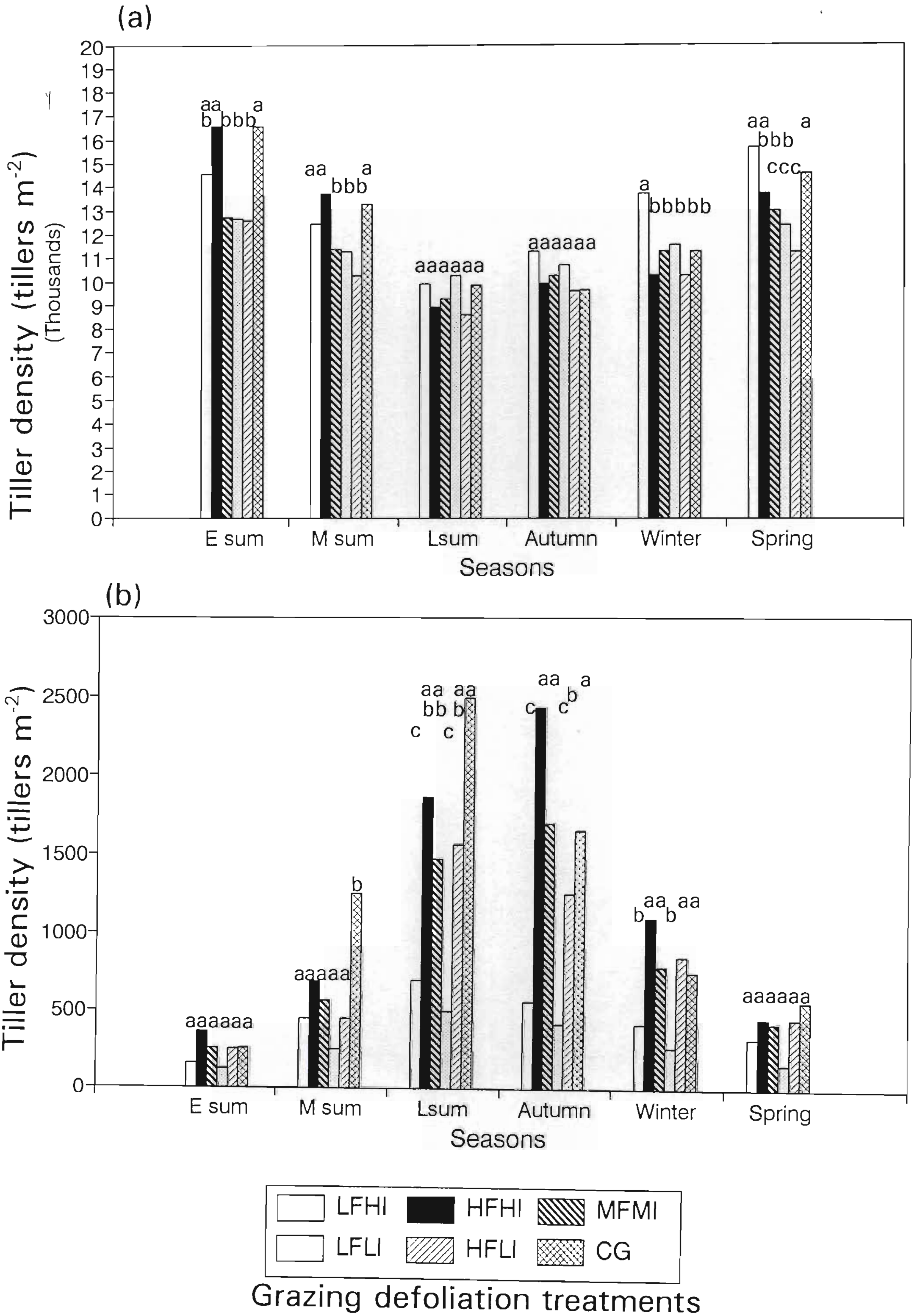


Figure 3.15 The effect of grazing defoliation on (a) perennial ryegrass tiller density, and (b) weed species tiller density during 1993/94. Bars with

Table 3.16 The proportional contribution (%) of weed species tiller density to total sward tiller density

Grazing treatments

	LFHI	HFHI	MFMI	LFLI	HFLI	CG
	Proportional contribution (%)					
1992/93						
Early summer	2	1	1	1	2	2
Mid summer	1	4	4	1	2	4
Late summer	3	5	5	3	3	6
Autumn	1	4	2	1	4	4
Winter	0	1	1	1	2	2
Spring	1	1	1	0	1	1
1993/94						
Early summer	1	2	2	1	2	2
Mid summer	4	5	5	2	4	9
Late summer	7	17	14	5	15	20
Autumn	5	20	14	4	12	15
Winter	3	10	7	2	8	6
Spring	2	3	3	1	4	4

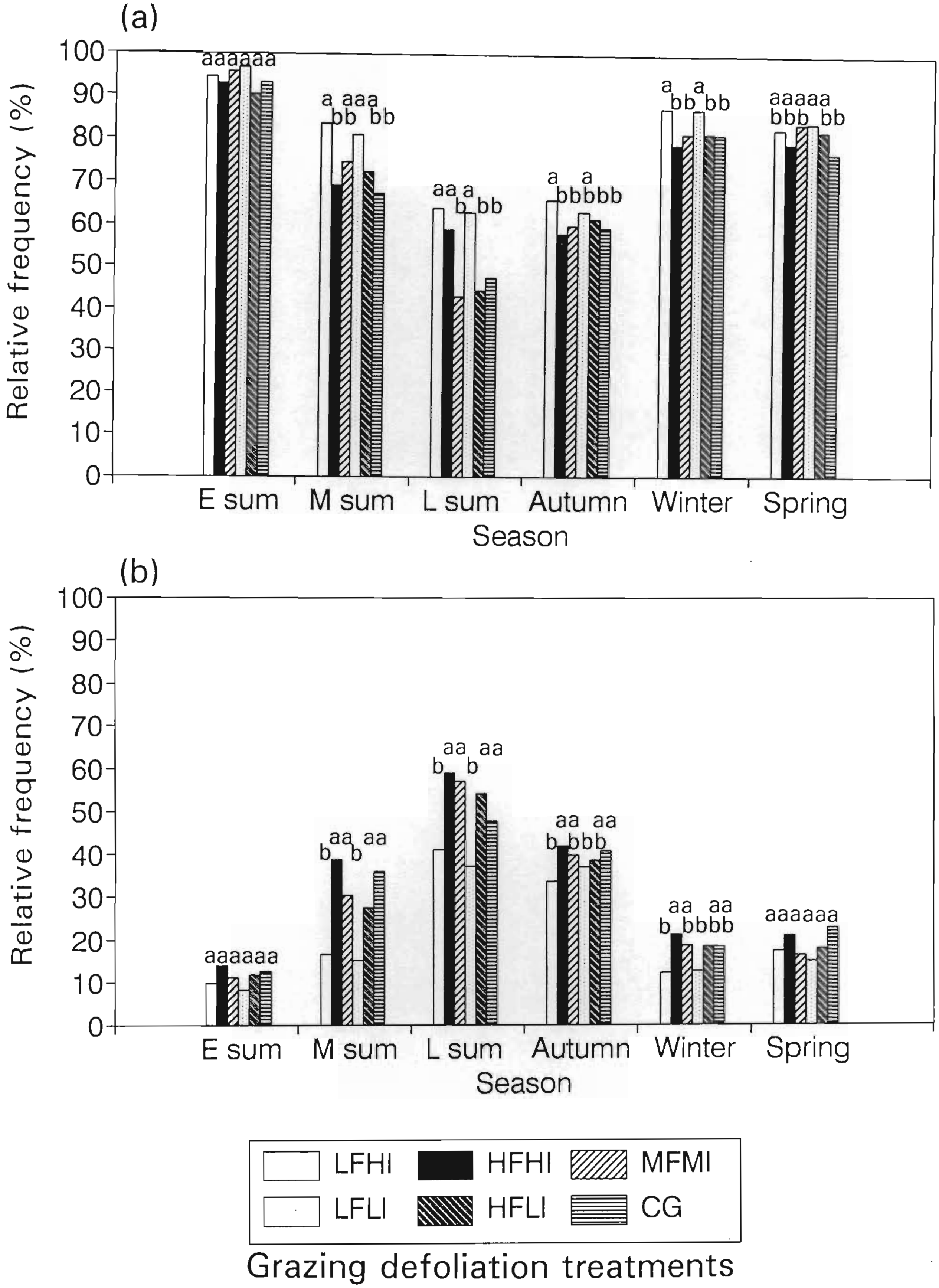


Figure 3.16 The effect of grazing defoliation on (a) the relative frequency of perennial ryegrass, and (b) the relative frequency of weed species during 1993/94. Bars with letters in common are not significantly different (P>0.05).

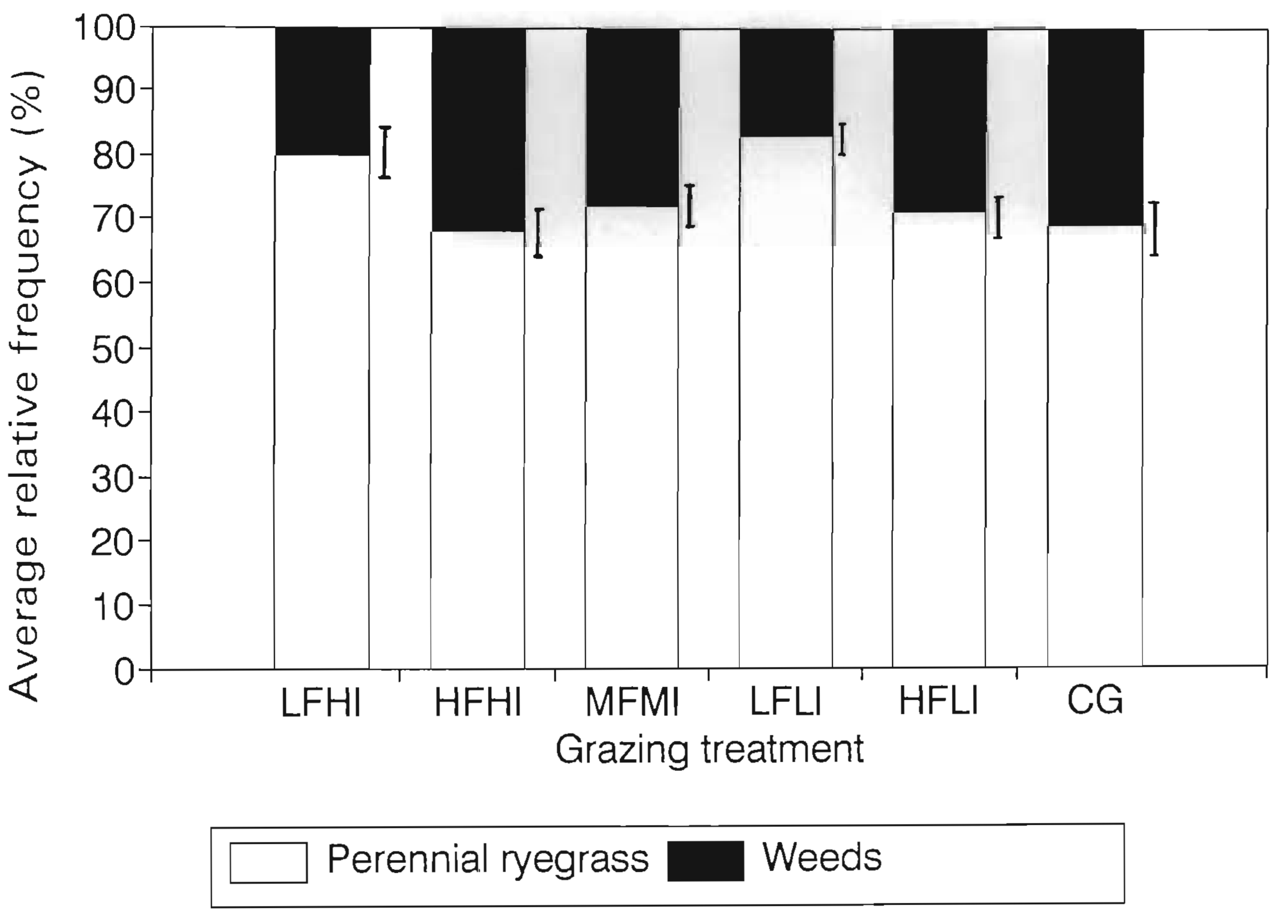


Figure 3.17 The effect of grazing defoliation on the average (six seasonal observations) relative frequency of perennial ryegrass and weed species during 1993/94. Standard error of each mean indicated by the vertical bars.

Invasive grass weed species encountered in the perennial ryegrass pastures were tropical species such as *Digitaria sanguinalis, Eleusine indica* and *Eragrostis curvula* (Table 3.15). Broadleaved weed species and sedges, relative to the grasses, formed a small frequency of the total weed species group and were therefore not identified individually. *Digitaria sanguinalis, Eleusine indica* and *Eragrostis curvula* were the most commonly encountered weed species in the pastures (Table 3.15). For the purpose of further analyses regarding weeds, all species encountered were grouped together and no analyses were conducted to test if certain treatments favoured the encroachment of a particular weed species. The reason for this was that some plots were more prone to invasion by certain weed species than others due to their position in the trial. For example, some plots were located adjacent to *Eragrostis curvula* and *Eragrostis tef* pastures and were more susceptible to invasion by this species. It was, therefore, not considered possible to conclude which species was more likely to invade perennial ryegrass in response to a given treatment.

While detailed discussion concerning perennial ryegrass tiller densities (estimated from non-destructively harvested data) has taken place (section 3.3.3), some additional discussion based on destructively harvested data is dealt with here. The trends established earlier, whereby treatments frequently and intensively defoliated (e.g. HFHI and CG), exhibited higher tiller densities than treatments less frequently and more leniently defoliated (e.g. LFHI and MFMI) were also evident in these data sets (Figures 3.14(a) & 3.15(a)). The LFHI, HFHI and CG treatments had perennial ryegrass tiller densities higher ($P \leq 0.05$) than the LFLI, MFMI and HFLI treatments, except during the summer period of the second year (Figures 3.14(a) & 3.15(a)). In addition, perennial ryegrass tiller densities, irrespective of treatment, decreased over the mid to late summer period in both years. This response is presumably due to the poor tillering ability of perennial ryegrass during the summer period, together with high tiller mortalities that occur at this time (section 3.3.3).

Trends for tiller densities of weed species over time were different to those for perennial ryegrass. Generally, the tiller densities of weed species, irrespective of treatment effects, increased over the mid summer to autumn period. This trend was observed during both years (Figures 3.14(b) & 3.15(b)). Treatments that were frequently and intensively defoliated (e.g. HFHI and CG) exhibited higher ($P \leq 0.05$) weed tiller densities over the late summer to autumn period during the first year (Figure 3.14(b)) and over the mid summer to autumn period during the second year (Figure 3.15(b)), than treatments infrequently defoliated (e.g. LFHI and LFLI). There was no significant ($P > 0.05$) difference between the two levels of grazing intensity (the LFHI and LFLI treatments). This suggests that a low defoliation frequency is more important than a low defoliation intensity, if weed tiller densities are to be minimized.

It also appears that the incidence of weed invasion is more pronounced during summer, particularly for treatments frequently defoliated (e.g. HFHI and CG) (Figures 3.14(b) & 3.15(b)). Weeda and During (1987) reported that high grazing intensity in early summer, even in temperate environments, increases the persistence of tropical species (e.g. *Paspalum dilatatum*) at the expense of perennial ryegrass. This effect is marked where intensive grazing is continued throughout the summer. Fulkerson *et al.* (1993) conducted their research under sub-tropical conditions and found that significantly more tropical grass species invade perennial ryegrass pastures during summer when a high cutting frequency (every two weeks) is adopted, than a low cutting frequency (every four weeks). It appears that increased temperatures during summer, which tend to favour tropical weed species, allows them to take advantage of the weakened competition from the perennial ryegrass (Fulkerson *et al.* 1993). The negative effects of high summer temperatures (> 25 °C; Table 3.2) of reducing perennial ryegrass growth (Cooper & Tainton 1968) are also believed to be a contributing factor to the observed weed invasion for the trial at Ukulinga. Furthermore, tropical grass species (e.g. *Cynodon dactylon* and *Eragrostis curvula*) have an optimum temperature for growth in the range of 30 to 35 °C (Cooper & Tainton 1968; Vogel *et al.* 1978).

The contribution of weed tiller density to total sward tiller density during 1992/93 was not markedly different for any particular treatment (Table 3.16). However, during the late summer and autumn periods of 1993/94 HFHI, MFMI, HFLI and CG treatments had distinctly higher (up to 20, 14, 15 and 20%, respectively) proportional weed tiller densities than LFHI and LFLI treatments (Table 3.16). For the LFHI and LFLI treatments, weed tiller density did not exceed 7% of the total sward tiller density in either year. These results further substantiate the earlier suggestion that a low defoliation frequency is more important than a low defoliation intensity, if weed tiller densities are to be minimized.

Tiller density data (Figures 3.14 & 3.15) were complemented with data on the relative frequencies of perennial ryegrass and weed species during the second year (Figure 3.16). The relative frequency of perennial ryegrass ranged from 43% (MFMI) during late summer to 98% (LFLI) during early summer (Figure 3.16(a)). For weed species on the other hand, the relative frequency ranged from 8% (LFLI) during early summer to 60% (HFHI) during late summer (Figure 3.16(b)). In terms of relative frequency of perennial ryegrass, the LFHI and LFLI treatments were generally significantly ($P \leq 0.05$) greater than the other treatments (e.g. HFHI and MFMI) during the mid summer to winter period (Figure 3.16(a)). Conversely, the LFHI and LFLI treatments exhibited a significantly ($P \leq 0.05$) lower relative frequency of weed species during the mid summer to winter period (Figure 3.16(b)). These observations are further supported by a treatment comparison of the average relative frequencies of perennial ryegrass and weed species for the six seasonal periods (Figure 3.17). These averages illustrate that the LFHI and LFLI treatments had higher relative frequencies of perennial ryegrass (81 and 83%, respectively) than the HFHI, MFMI, HFLI and CG treatments (68, 72, 71 and 69%, respectively) (Figure 3.17).

These data (Figures 3.14; 3.15, 3.16 & 3.17) suggest that adopting a low frequency of grazing defoliation is an important management tool aiding in the suppression of invading weed species, particularly during summer. Such an observation has also been reported for temperate conditions in New Zealand. Harris and Brougham (1968) found that perennial ryegrass swards developing under lenient and moderate grazing systems remain as virtually pure stands. Under such grazing systems, Harris and Thomas (1972) contended that ryegrass markedly suppresses potential weed invaders. In swards developing under severe or continuous close grazing, marked ingress of weed species occurs (Harris & Thomas 1972).

Such observations have been attributed to the lower growth rate of invading weed species during establishment, and their shading by the more erect ryegrass plants (Harris & Thomas 1972). These authors suggested that the rate of ingress of weeds can be checked by increasing the interval between defoliations as this increases over-topping and shading of invaders.

3.6.5 Conclusions

The incidence of weed ingression is higher over the summer period than during the autumn, winter and spring periods, presumably because most potential weed species are tropical grasses and are relatively inactive during autumn, winter and spring.

The results presented indicate that the invasion of perennial ryegrass swards by weed species, particularly during the summer period (October to March), can at least be partially controlled by sufficiently long intervals between defoliations.

3.7 Root development

3.7.1 Introduction

It has been suggested (Fulkerson *et al.* 1993) that a factor contributing to poor persistence in perennial ryegrass is the apparent lack of root development, particularly during the summer. In perennial ryegrass the growth and production of roots fluctuates between seasons. Garwood (1969) found that a surge in root production coincided with the spring tiller 'flush', while the onset of the reproductive phase resulted in the death of roots.

Besides root development being linked to the pattern of tiller development, restricted root development could be due to drainage or soil compaction problems (Edmond 1958a; 1958b; Drew 1983), grazing management (Evans 1972) and N applications (Steen 1984). Evans (1971) reported that severe defoliation resulted in reduced root elongation, while repeated defoliation caused a prolonged depression of root elongation. In addition to these effects, defoliation has also been shown to decrease soluble carbohydrates in the roots (Evans 1972; 1973).

The primary objective of this investigation was to estimate the effect of grazing management (in terms of both frequency and intensity) on root production at varying depths in the soil profile.

3.7.2 Sampling procedure

A soil corer with an internal cutting-edge diameter of 10 cm was used to take root core samples to a depth of 20 cm. Four randomly placed core samples were taken per plot (i.e. 16 samples per treatment). If the corer was positioned within 20 cm of a 'weed' species it was relocated to avoid sampling roots from 'weed' species. Soil cores were sectioned to allow comparisons of root DM production in four soil depth categories: 0 - 5 cm, 5 - 10 cm, 10 - 20 cm and 0 - 20 cm.

Separating roots from the soil was a time-consuming process and not all the harvested samples could be processed at once. Cores were sometimes frozen to prevent decomposition of OM until they could be processed (Troughton 1981). Two sieves with mesh diameters of 2000 and 720 *um* were used to separate roots from the soil. This process involved removal of herbage at the soil surface and sectioning the core into respective soil depth categories. Individual sections of the core were then soaked for several hours before separating roots from the soil using water, hand action and the sieves.

Collected root material was then dried to a constant weight at 70 °C. After this, samples were ashed at 550 °C and results expressed as the weight of OM per unit volume of soil. Ashing was deemed necessary to reduce error associated with the difficulty of removing all soil particles from roots (Troughton 1981).

Roots were sampled on five occasions during the trial, namely: November 1992, April and September 1993, February and September 1994. Unfortunately, the amount of time required to process all samples from a single sampling occasion (approximately two weeks), made it impractical to use this process monthly to gain an accurate picture of the fluctuations in root development with time.

3.7.3 Data analysis

An inspection of the data characteristics indicated that these data required a natural logarithmic transformation to normalize variables for analysis of variance (randomized blocks design incorporating nested sub-sampling). Least significance difference tests were applied to treatment means (Steel & Torrié 1981).

3.7.4 Results and discussion

The response of roots to various grazing defoliation treatments was estimated by the weight of root OM per unit volume of soil. These results are presented for both transformed (Figure 3.18) and untransformed (Figure 3.19) data. Relative proportions of root OM occurring in each soil depth category for each of the sampling periods are given (Table 3.17).

Immediately evident (Figure 3.18) was that during the establishment year (as estimated by the November 1992, April 1993 and September 1993 sampling periods) no significant (P>0.05) treatment differences were encountered. In addition, no distinguishable trends were observed for the November 1992 and April 1993 root harvest periods. By September 1993, however, a trend was beginning to manifest itself, whereby treatments infrequently grazed (LFHI and LFHI) had higher root OM per unit volume in both the 0 - 5 and 0 - 20 cm depth categories than treatments more frequently grazed (HFHI, MFMI, HFLI and CG) (Figure 3.18). Lack of significant treatment effects during the establishment year are presumably because treatment effects had not had sufficient time to express themselves, and because the root systems of the pastures were still developing. This is evident from the untransformed treatment means (Figure 3.19) which clearly indicate that the root systems of all treatments were increasing in size during the establishment year (i.e. for observation periods: November 1992, April 1993 and September 1993).

A second explanation for a lack of significant treatment effects during the first year is the possibility of data variability. Root data are notoriously variable (high CV's) in spite of

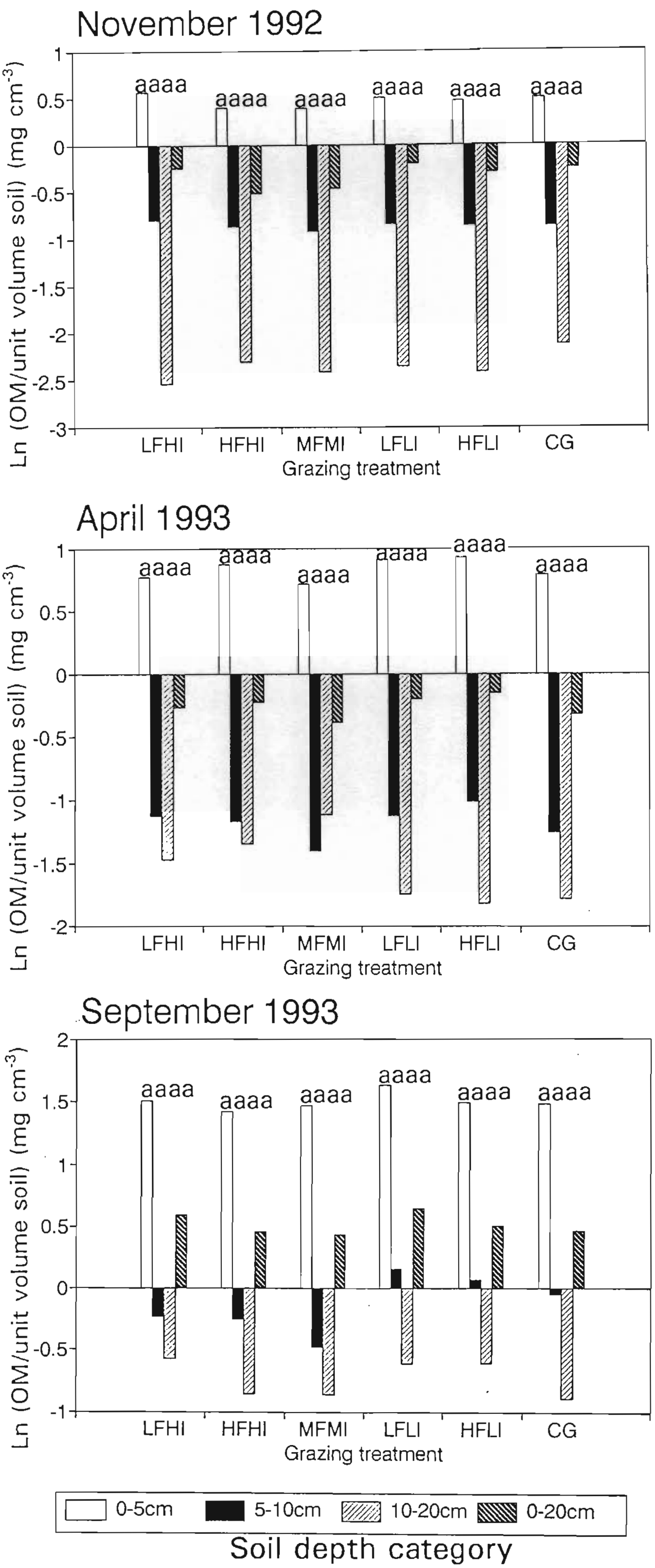


Figure 3.18 Weight of root OM per unit volume of soil (natural log transformed) as assessed in November 1992, April 1993, September 1993, February 1994 and September 1994 for each of the six treatments at four depth categories. Bars with letters in

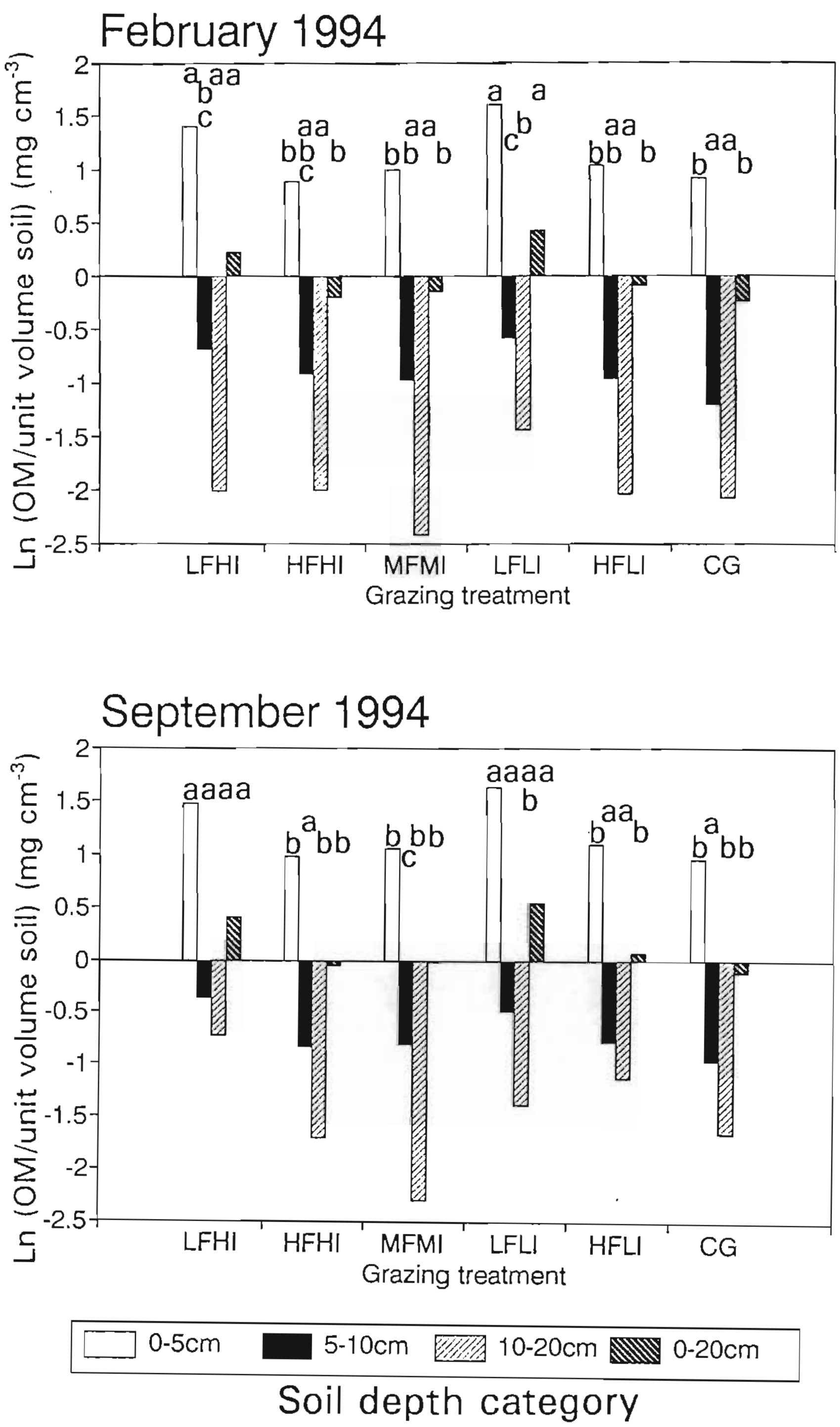


Figure 3.18 continued.

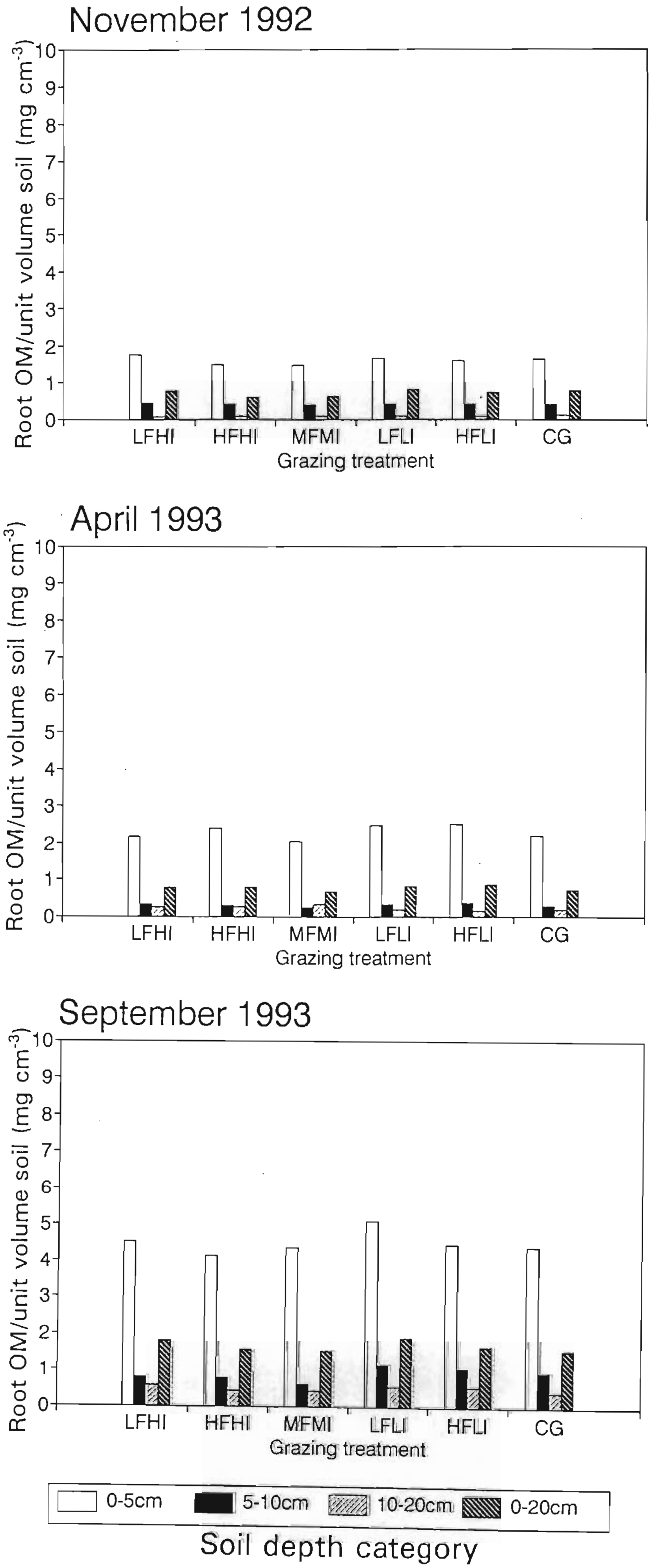


Figure 3.19 Weight of root OM per unit volume of soil (untransformed treatment means) as assessed in November 1993, April 1993, September 1993

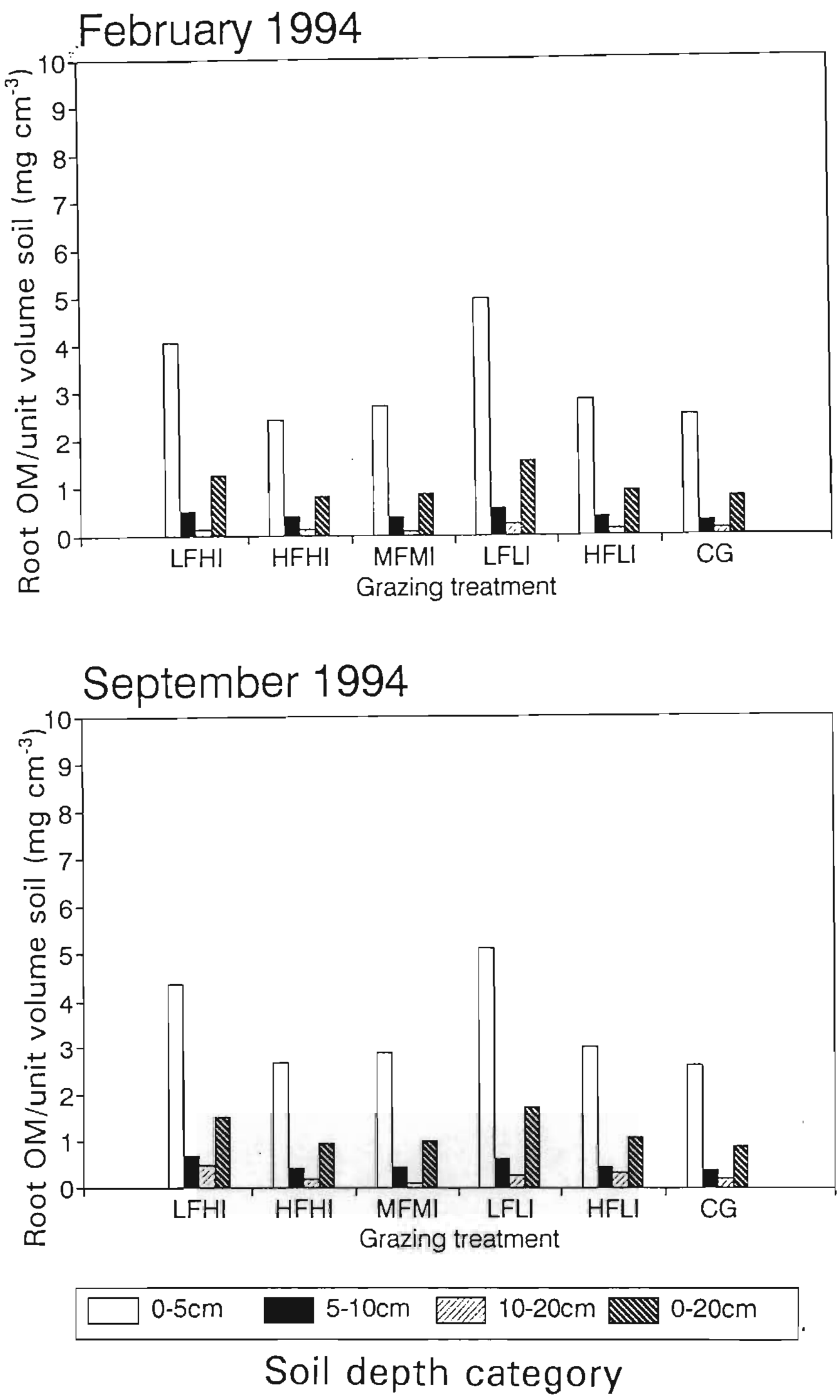


Figure 3.19 continued.

Table 3.17 Relative proportion (%) of root OM per unit volume of soil in each soil depth category

Sampling period	Soil depth category (cm)	Treatment[1]					
		LFHI	HFHI	MFMI	LFLI	HFLI	CG
		Relative proportion (%)					
November 1992	0 - 5	74	71	72	73	73	72
	5 - 10	19	20	19	19	19	18
	10 - 20	7	9	9	8	8	10
	0 - 20	100	100	100	100	100	100
April 1993	0 - 5	74	74	70	79	79	78
	5 - 10	11	10	8	10	11	10
	10 - 20	15	16	22	11	10	12
	0 - 20	100	100	100	100	100	100
September 1993	0 - 5	70	72	75	69	67	71
	5 - 10	12	13	11	16	16	16
	10 - 20	18	15	14	15	17	13
	0 - 20	100	100	100	100	100	100
February 1994	0 - 5	84	78	83	83	82	82
	5 - 10	10	13	12	9	11	10
	10 - 20	6	9	5	8	7	8
	0 - 20	100	100	100	100	100	100
September 1994	0 - 5	73	77	82	82	73	77
	5 - 10	11	13	13	10	11	12
	10 - 20	16	10	5	8	16	11
	0 - 20	100	100	100	100	100	100

exercising care in their collection and processing (Troughton 1981).

During the second year, however, treatment effects were well expressed. The weak trend of a higher root OM per unit volume of soil under low defoliation frequency treatments (LFHI and LFLI) than under high defoliation frequency treatments (HFHI, MFMI, HFLI and CG) for September 1993 became a significant trend ($P \leq 0.05$) for the February 1994 and September 1994 harvest periods (Fig 3.18). This trend was evident for root OM per unit volume of soil in the 0 - 5 and 0 - 20 cm soil depth categories, but not in the 5 - 10 and 10 - 20 cm depth categories. This was perhaps a result of high errors in the data associated with very low weights of root OM in the 5 - 10 and 10 - 20 cm depth categories relative to the 0 - 5 and 0 - 20 cm depth categories. These relative weight comparisons were also evident for the untransformed treatment means (Figure 3.19).

While defoliation frequency produced significant ($P \leq 0.05$) treatment effects, the level of grazing intensity did not ($P > 0.05$) (Figure 3.18). It would appear, therefore, that defoliation frequency is more important than defoliation intensity in influencing root production in perennial ryegrass under sub-tropical conditions at Ukulinga. This is surprising since root growth is generally retarded when plants are defoliated. The greater the frequency and/or intensity of defoliation, the more obvious is the reduction in root growth (Christiansen & Svejcar 1988; Fulkerson *et al*. 1993). Fulkerson *et al*. (1993), working under sub-tropical conditions, reported lower root production in summer at more frequent cutting (every two weeks) than at less frequent cutting (every four weeks). On the other hand, Davidson and Milthorpe (1966) showed that the greater the level of defoliation intensity (cutting) applied to *Dactylis glomerata*, the longer it took for roots to regain their capacity to take up minerals.

In terms of seasonal effects, root production was found to decline as the proportion of fertile tillers increased (i.e. during the reproductive phase in late spring - early summer). This response during flowering was also observed during an earlier study by Soper (1958). This researcher contended that the greater the number of flower heads, the shorter the life of the roots after the flower heads die back. Interestingly, after mid summer when many new tillers are formed and these numbers rise almost to the spring peak (a response found to be pronounced in the United Kingdom), the number of new roots does not rise correspondingly. At this time of the year, external factors may have a more direct effect on the production of adventitious roots, for example, when high soil surface temperatures restrict the development of root primordia at an early stage of growth (Garwood 1968). Often, new tillers produced during autumn in the United Kingdom must rely on the established roots of the parent tiller for water and nutrients until soil conditions become more suitable for root growth. In contrast, research conducted in New Zealand showed that root production in perennial ryegrass was highest during autumn, falling gradually during winter to a minimum in spring and summer (Caradus & Evans 1977). Although root development was not monitored on a monthly basis for the current trial, it was evident (Figure 3.19) that such seasonal root development was expressed. Root OM per unit volume of soil was relatively lower for the February 1994 (late summer) observation period than for the September 1993 (spring) and September 1994 periods. From these somewhat inconclusive results on seasonal effects, and the aforementioned review of published data, it can be argued that perennial ryegrass is in a weaker state (in terms of having a smaller root system) during summer than during the spring period.

In considering the distribution of perennial ryegrass roots at varying soil depths, it was observed that of the total root mass sampled, the bulk (69 to 84%) occurred in the top 5 cm of the soil (Table 3.17). Such a condition serves to emphasize the importance of frequent, light irrigation scheduling.

In the 5 - 10 cm soil depth category, root mass ranged from a high of 20% (LFHI) during November 1992 to a low of 8% (MFMI) during April 1993 (Table 3.17). Generally, however, root mass in this category (5 - 10 cm) remained at about 12% during the second year for all treatments.

For the 10 - 20 cm depth category, root mass was reduced from a high of 11 to 22% during April 1993 to a low of 5 to 9% during February 1994 (Table 3.17). The general increase in the proportion of roots in the top 5 cm of the soil, and a decrease in the 10 - 20 cm category during the second year, may indicate an increase in soil compaction for all treatments, although this was not monitored. Soil compaction is believed to arise where irrigation and a period of occupation by grazing animals coincide. The hoof action of the animal on the moistened soil surface leads to compaction and subsequent DM yield reduction (Edmond 1963; 1964; Curll & Wilkins 1983). Because of the strict application of the grazing treatments and irrigation scheduling, there were numerous occasions when the pasture was occupied by sheep during an irrigation period. This should, as far as possible, be avoided.

3.7.5 Conclusions

The root system of perennial ryegrass continued to develop throughout the establishment year, with treatment effects becoming apparent only during the second year. These effects favour the maintenance of a low grazing frequency as part of the management programme to promote a large and healthy root system. Surprisingly, grazing intensity appears not to affect root OM per unit volume of soil.

Although the evidence from the current trial is inconclusive as far as seasonal effects on root development are concerned, indications are that a larger root system is supported in spring than summer. This would suggest that perennial ryegrass is at its weakest (in terms of having a smaller root system) during summer than during spring, and would thus require careful management over the summer period.

Perennial ryegrass is extremely shallow-rooted, with approximately 75% of the root mass occurring in the top 5 cm of the soil. This stresses the need to pay careful attention to irrigation scheduling.

CHAPTER 4

INFLUENCE OF APPLIED NITROGEN ON PERENNIAL RYEGRASS DURING THE ESTABLISHMENT YEAR

4.1 Introduction

It is widely accepted that pasture productivity (Holliday & Wilman 1965; Curll & Wilkins 1982) and quality (Frame & Hunt 1971; Wilman *et al.* 1977) is affected by the level of applied N. Fertilization of pastures with N has been observed to increase DM yields and herbage protein under a wide range of environmental conditions (Ashford & Troelsen 1965; Castle & Reid 1965; Chestnutt *et al.* 1977). With respect to perennial ryegrass under the sub-tropical conditions of South Africa, however, there is very little information regarding its fertilization. Only recently has some data on N fertilization of perennial ryegrass emerged for South African conditions (Eckard 1994).

In Europe, fertilizer N has been used in increasing amounts in intensively managed livestock systems to enhance profitability, either by increasing DM yields or by reducing production costs by substitution of concentrates (Lazenby 1981). The use of high N inputs on intensively managed pasture systems has also been a common practice on farms in South Africa.

It was speculated, however, that the high N level (480 kg N ha^{-1} a^{-1}) applied to the grazing trial (CHAPTER 3) may have inhibited the persistency of this pasture. Many of the intensive South African pastures are heavily fertilized with N (300 - 400 kg N ha^{-1} a^{-1}) (CHAPTER 2) and, unlike those in New Zealand, are not usually clover-based. Application levels of N onto perennial ryegrass-clover pastures in New Zealand may be as low as 50 kg

N ha^{-1} (Clark 1993a). Observation has shown that higher levels of N may indeed limit the persistency of perennial ryegrass in New Zealand (P.R. Ball 1993, personal communication, Grasslands Division, DSIR, Palmerston North, New Zealand). It was decided, therefore, to test the effects of a range of applied N levels on the survival potential of perennial ryegrass during the establishment year. The study was also initiated to gain additional information on performance aspects (in terms of DM production and quality) of perennial ryegrass under grazing defoliation using sheep. Of greater importance, however, was the objective of establishing a lower and upper N level at which tiller population densities, perennial ryegrass vigour, prevention of weed invasion and root development may be enhanced.

4.2 Experimental procedure

This section describes the study site, the applied N treatments, the design and field lay-out of the trial. Specific experimental details such as sampling procedures and analyses pertaining to individual objectives that the study addresses are described in the relevant sections.

4.2.1 Study area

The trial was conducted at the University of Natal's research farm, Ukulinga (see section 3.2.1 for specifications).

Perennial ryegrass (cultivar Ellett) was established on 9 September 1993 on a Westleigh soil form (MacVicar *et al* 1977) with an average depth of 300 mm and a slope of 5%. The soil properties and aspect of the site were similar to those for the grazing trial (see section 3.2.1), and can therefore also be described as less than ideal for perennial ryegrass.

Soil nutrient status was maintained at > 20 mg L^{-1} and > 150 mg L^{-1} for P and K, respectively (Manson *et al*. 1990). A soil test conducted prior to establishment, revealed that P was limiting while K and soil acid saturation were not (Table 4.1). A 'pop up' dressing of 300 kg ha^{-1} of 2:3:2 (22) was applied at establishment and the outstanding soil P balance corrected (4 weeks after germination) using 250 kg ha^{-1} of DAP (18% N, 20% P). Irrigation was applied at 25 mm week^{-1}, usually as two applications of 12.5 mm every three to four days during the hot summer months.

Table 4.1 Results of a soil test conducted for the N trial

Sample density (g ml^{-1})	P	K	Ca	Mg	Acid Sat. (%)	pH (KCl)
	........mg L^{-1}.........					
1) 1.12	7	264	1920	404	0.9	4.94

1) test conducted in August 1993

Since the primary concern of this trial was to establish the short-term effects of applied N on perennial ryegrass populations, it was important to apply grazing management that would optimize tiller production and persistence. Thus, the entire site was rotationally grazed at the frequency and intensity level identified by the grazing trial (one year's data only) as being favourable in terms of maximum tiller production (treatment HFHI, Table 3.3). Further justification for adopting a high grazing frequency and intensity was based on results from research conducted by Holliday and Wilman (1965). Results from infrequent cutting of perennial ryegrass suggest that the greater the supply of N (up to a certain level) the greater the rate of growth and the earlier ceiling DM yield is attained. If the crop is left to stand beyond the optimum point, rate of growth declines and may become negative and the advantage of a higher level of N is lost. Added to this is the negative effect that shading has on tiller production (Mitchell 1953); this effect is enhanced if defoliation is infrequent and lenient (Grant *et al.* 1981; Davies & Thomas 1983).

4.2.2 Treatments

Treatments comprised six levels of N namely:

A = 120 kg N ha^{-1};

B = 240 kg N ha^{-1};

C = 360 kg N ha^{-1};

D = 480 kg N ha^{-1};

E = 600 kg N ha^{-1}; and

F = 720 kg N ha^{-1}.

These N levels were applied in 12 equal monthly dressings.

4.2.3 Experimental design and field lay-out

Treatments were replicated three times and randomly allocated to 18 plots, each 15 m X 15 m (225 m^2). The field lay-out of the experimental plots is given (Figure 4.1). Sheep were used to graze the herbage to the defined defoliation intensity level as quickly as possible (one to two days). The actual numbers of sheep required to achieve the defined defoliation were based on readings taken with a pasture disc meter (Bransby & Tainton 1977) (see section 3.2.4).

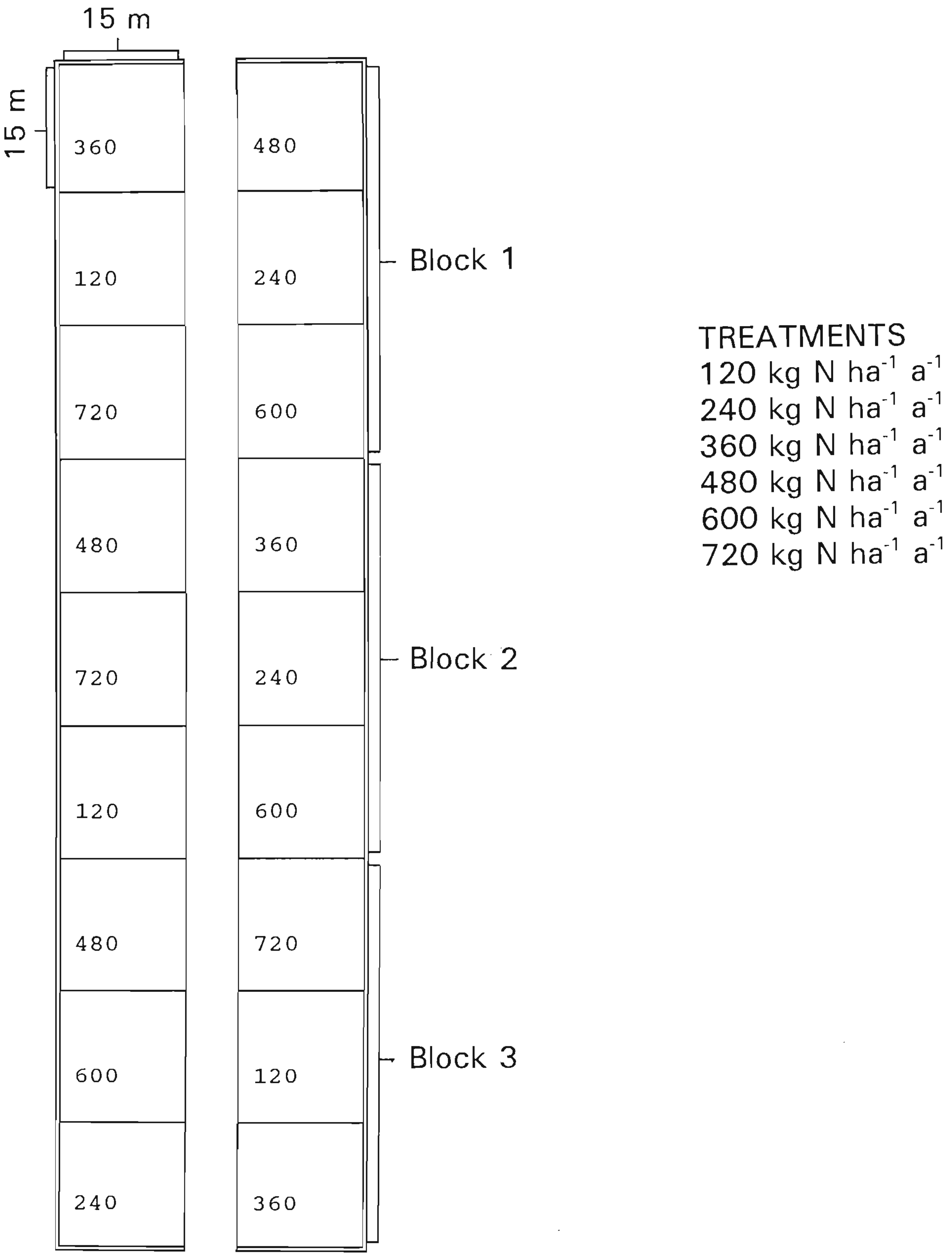


Figure 4.1 Field lay-out of the nitrogen trial.

4.3 Perennial ryegrass tiller densities

4.3.1 Introduction

Korte *et al.* (1982) suggested that differences in tiller density are brought about by changes in the rate of tiller generation and tiller death. The effects that both frequency and intensity of defoliation have on tillering rates and deaths have been well established for temperate environments (e.g. Grant *et al.* 1981; Korte 1986) and these principles tend to be applied under the sub-tropical conditions of South Africa (Goodenough *et al.* 1991). An important question, however, remains unanswered. What is the influence of applied N on perennial ryegrass tiller densities? Even for temperate environments, this question has received only limited attention and has resulted in contradictory observations. For example, increasing the level of applied N is said to be detrimental to the survival of perennial ryegrass (Brougham 1958; Harris & Lazenby 1977). Alternatively, increasing the level of applied N has resulted in an increase in the level of tiller production (Davies 1971; Curll & Wilkins 1982; Thomas *et al.* 1990).

It is apparent from the literature that little emphasis is placed on this area of research in New Zealand because of the reliance on clover as a N source. What requires elucidation under South African conditions, therefore, where much of the N source for pastures is applied as chemical fertilizer, is the effect of this applied N on tiller population densities. Ideally, in this trial, tiller dynamics should have been monitored using marked tillers in fixed quadrats. This, however, was not possible because of the time constraints imposed by the grazing trial (CHAPTER 3). The objective of monitoring vegetative, reproductive and aerial tiller densities in perennial ryegrass receiving different levels of applied N, was therefore undertaken using a destructive sampling procedure.

4.3.2 Sampling procedure

For this study, ten randomly placed quadrats per plot (10 cm diameter: 78.54 cm^2) were harvested at monthly intervals. The material was then moved to the laboratory for subsequent tiller counts and separation into tiller categories (i.e. vegetative, reproductive and aerial).

4.3.3 Data analysis

Perennial ryegrass reproductive and aerial tiller density data sets were square-root transformed to normalize variables for analysis of variance (Steel & Torrie 1981). Total perennial ryegrass tiller densities, on the other hand, did not require transformation. Data were subjected to analysis of variance (randomized blocks design incorporating nested sub-sampling), and LSD tests were applied to treatment means (Steel & Torrie 1981).

4.3.4 Results and discussion

Total perennial ryegrass tiller densities are presented in Figure 4.2. Both transformed and untransformed treatment means for perennial ryegrass reproductive and aerial tillers are presented in Figures 4.3 and 4.4.

Total (i.e. vegetative, reproductive and aerial) perennial ryegrass tiller densities ranged from 3 500 tillers m^{-2} (at 120 kg N ha^{-1} a^{-1}) during April 1994 to 17 800 tillers m^{-2} (at 600 kg N ha^{-1} a^{-1}) during August 1994 (Figure 4.2). While there was no apparent effect of N on tiller density during the October observation period ($P>0.05$), a response became significantly ($P\leq0.05$) apparent from November onwards (Figure 4.2). There was very little difference ($P>0.05$) in perennial ryegrass tiller density between the 480 and 720 kg N ha^{-1} a^{-1} application levels.

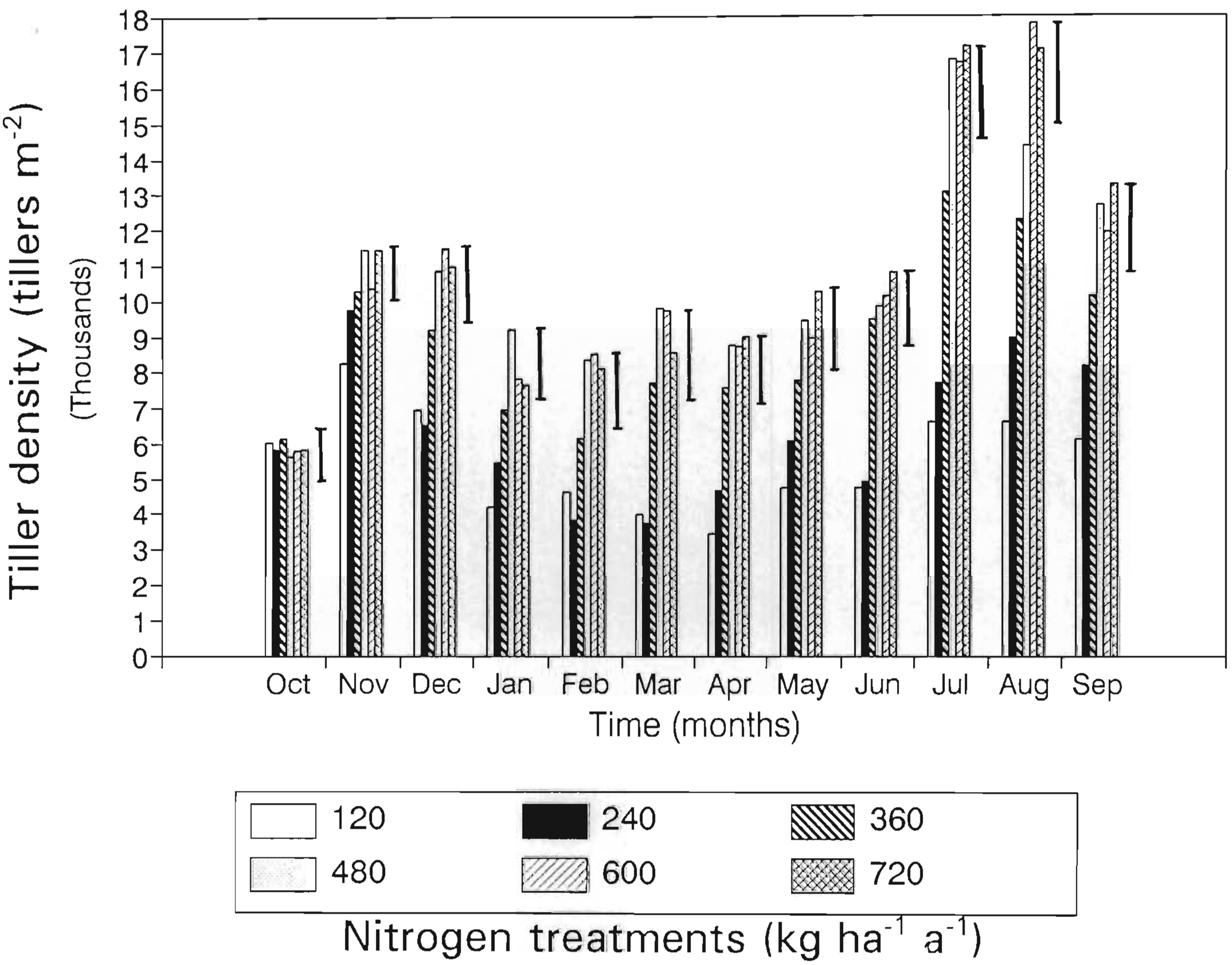


Figure 4.2 The effect of applied N on total perennial ryegrass tiller density. Vertical bars indicate the LSD (P=0.05) level.

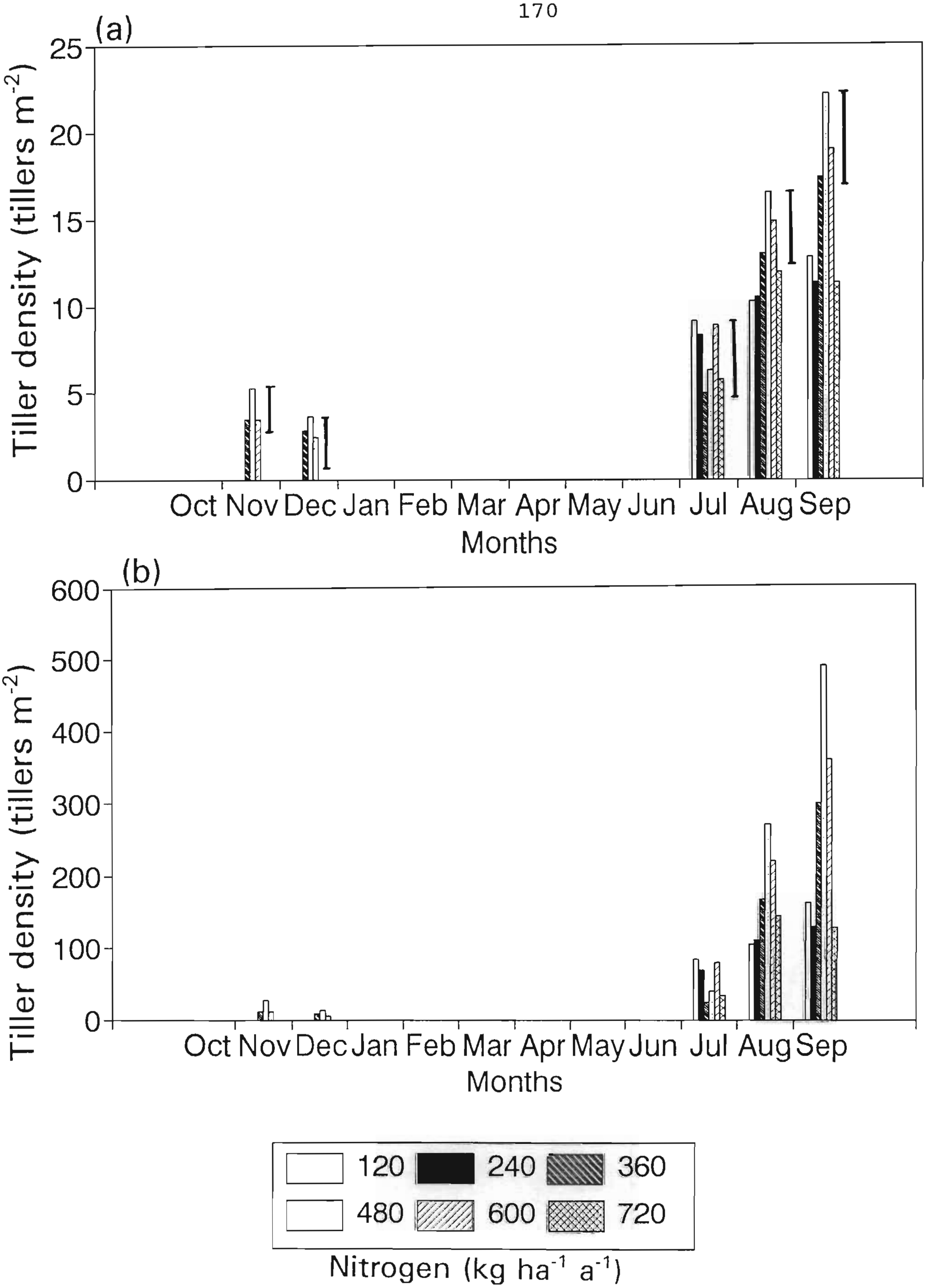


Figure 4.3 The effect of applied N on perennial ryegrass reproductive tiller density. (a) Square-root transformed (vertical bars indicate the LSD (P=0.05) level) and (b) untransformed data are illustrated.

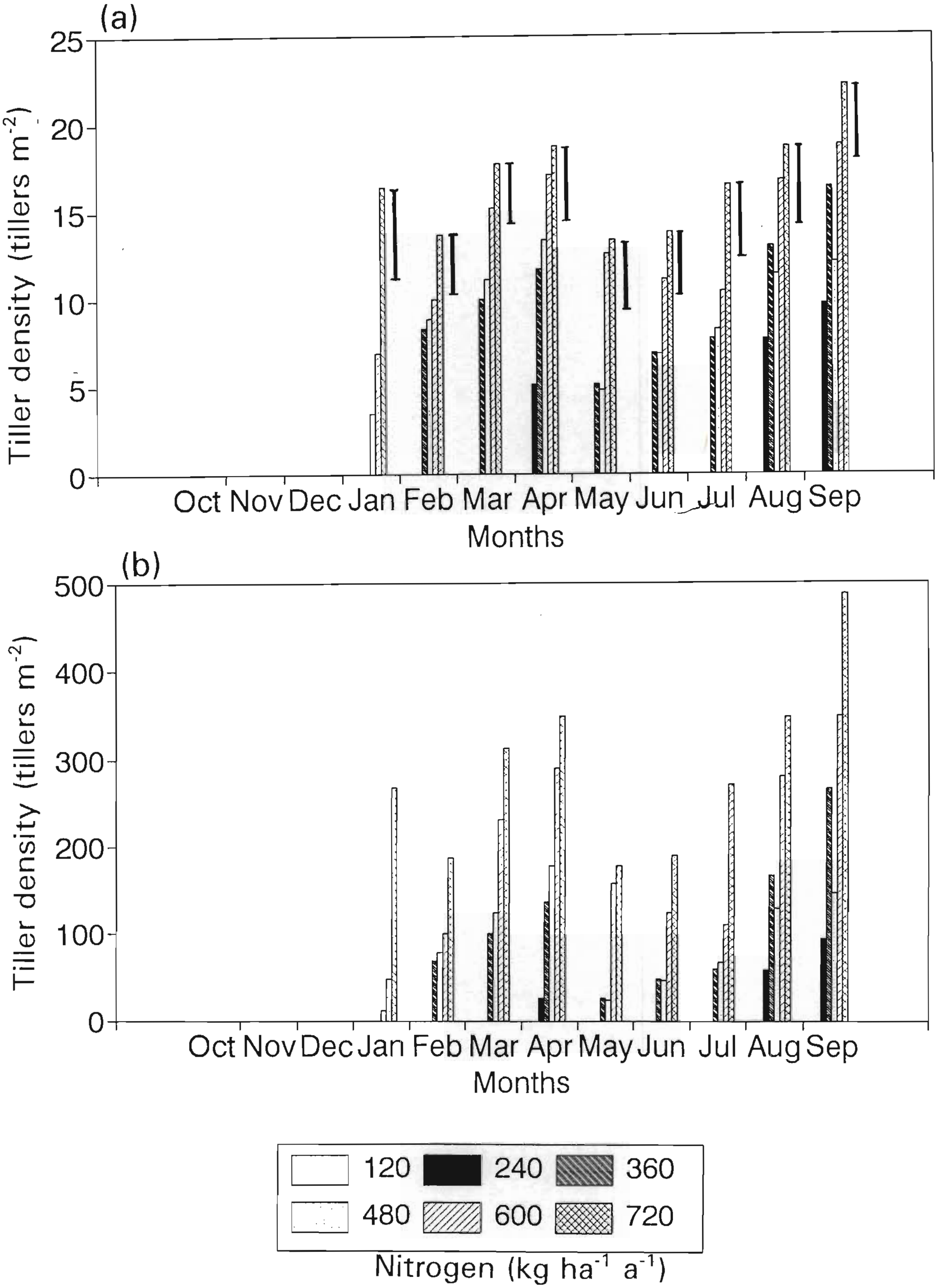


Figure 4.4 The effect of applied N on perennial ryegrass aerial tiller density. (a) Square-root transformed (vertical bars indicate the LSD (P=0.05) level) and (b) untransformed data are illustrated.

With the exception of the autumn period (April and May) when tiller densities were similar to those for summer, the seasonal trend in perennial ryegrass tiller density followed that established in the grazing trial (CHAPTER 3, section 3.3.3). Tiller densities were high for the late winter (July) and spring (August) periods relative to the mid to late summer (January to March) period (Figure 4.2). This is presumably in response to tillering flushes which have been observed to occur in perennial ryegrass during autumn and to a greater extent during spring (CHAPTER 3, section 3.3.3).

These results (Figure 4.2) corroborate the findings of other researchers. It has been found that applied N increases the number of perennial ryegrass tillers (Davies 1971; Wilman & Mares Martins 1977). For example, perennial ryegrass pastures that were continually grazed by sheep and received zero N over a five month period developed tiller densities of only 9 700 to 15 700 m^{-2} (Curll & Wilkins 1982). When 200 kg N ha^{-1} was applied, tiller densities increased to between 13 300 to 19 800 m^{-2}. Thomas *et al.* (1990) reported that higher perennial ryegrass tiller densities were observed in than out of urine patches and attributed this effect to additional N from urine.

Other researchers, however, have observed that high levels of applied N are detrimental to perennial ryegrass tiller population densities (Brougham 1958; Harris & Lazenby 1977). Harris and Lazenby (1977) found that low N rate swards were uniformly densely tillered, whereas high N rate swards consisted of clumps of tillers interspersed with considerable bare ground. Brougham (1958) reported that a high nutrient status encourages vigourous growth of the sward, often leading to an almost completely closed canopy. As spring advances, improvement in the light level above the sward is paralleled by a deterioration of the light level deep in the sward. Under such conditions, tillers at the base of the sward have a negative carbon balance and death is likely to occur (Ong 1978).

It is suggested that increased tiller densities at high levels of applied N are related to the increased sward DM production which has been reported for high N levels (Castle & Reid 1965; Davies 1971). Davies (1971) observed that higher leaf production per tiller was stimulated by increased N levels and it has been shown that tiller production in perennial ryegrass is closely related to leaf production (Mitchell 1953; Langer 1972).

Furthermore, it is suggested that the association of higher tiller densities with higher N levels occurs under conditions of frequent and intense defoliation, as was the case for this study. If defoliation is infrequent and lenient, base shading of the sward occurs, resulting in lower tiller densities (Mitchell 1953; Tainton 1981; Langer 1990). Also, infrequent lenient defoliation for swards receiving high N levels results in a ceiling yield (where the rate of tissue death equals the rate of tissue production (Holliday & Wilman 1965; Robson *et al.* 1988)) being achieved. Under such a condition, not only does base shading occur, but the rate of leaf production declines and so also the number of potential tillering sites (Davies 1971; Grant *et al.* 1981; Davies & Thomas 1983). If, on the other hand, defoliation is too frequent, tillering may also be reduced because of severely reduced plant vigour (Tainton 1981). Therefore, when interpreting the literature regarding the effect of applied N on tiller densities, defoliation frequency and intensity must also be taken into account.

A question that now arises is, if high tiller densities are stimulated by high levels of applied N, how viable are these tillers in terms of their potential to enhance the persistency of perennial ryegrass? This question is addressed in section 4.5.

Few reproductive tillers (and only for the 360, 480 and 600 kg N ha^{-1} a^{-1} treatments) were observed in November and December 1993 (Figure 4.3). These ranged from 6 (at 600 kg N ha^{-1} a^{-1}) to 27 (at 480 kg N ha^{-1} a^{-1}) tillers m^{-2} (Figure 4.3(b)). From July to September 1994, however, there was a marked increase in reproductive tiller density in all treatments. Over this period, reproductive tiller densities ranged from 24 (at 360 kg N ha^{-1} a^{-1}) in July to 489 (at 480 kg N ha^{-1} a^{-1}) tillers m^{-2} in September (Figure 4.3(b)). During August and September, the 360, 480 and 600 kg N ha^{-1} a^{-1} treatments had higher ($P \leq 0.05$) reproductive tiller densities than the 120, 240, and 720 kg N ha^{-1} a^{-1} treatments. It appears that both low levels of applied N (i.e. < 360 kg ha^{-1} a^{-1}) and high levels (i.e. > 600 kg ha^{-1} a^{-1}) limit reproductive tiller development in perennial ryegrass.

Generally, N is an important element required for maximising tillering. O'Brien (1960) stressed the importance of applied N to perennial ryegrass to encourage tillering. Tainton (1981) stated that low levels of soil N tend to promote tiller dormancy, while an increased tillering response is observed with increased levels of applied N in seed-producing forage crops, where N is applied in autumn to stimulate a crop of tillers for flowering in spring. No information is available on upper N levels and their associated influence on reproductive tillering for perennial ryegrass in South Africa. From these results (Figure 4.3), however, it appears that applied N levels above 240 kg ha^{-1} a^{-1} promote reproductive tiller densities, while levels above 600 kg ha^{-1} a^{-1} depress reproductive tiller densities. For Italian ryegrass under South African conditions, Field-Dodgson (1974) advocated 100 to 140 kg N ha^{-1} a^{-1} to promote maximum seed production, but cautioned that such levels of N need to be strategically applied (e.g. early spring).

In general, however, little importance can be placed on the level of reproductive tiller densities observed in this trial since their magnitude was (for all treatments) extremely low (Figure 4.3). The low magnitude of reproductive tiller densities is most likely a result of the high levels of grazing defoliation frequency and intensity adopted for this trial (see section 3.3.4.4). Such an effect of frequent and intense defoliation on reproductive stem development has also been reported by L'Huillier (1987).

Aerial tillers were observed from January to September 1994 (Figure 4.4). At 120 kg N ha^{-1} a^{-1} no aerial tillers were observed, while at 240 kg N ha^{-1} a^{-1} aerial tillers were observed only in April, August and September. Aerial tiller densities ranged from 12 (at 480 kg N ha^{-1} a^{-1}) in January to 487 (at 720 kg N ha^{-1} a^{-1}) tillers m^{-2} in September 1994 (Figure 4.4(b)). Generally, increasing levels of applied N increased ($P \leq 0.05$) aerial tiller density (Figure 4.4(a)), while at low levels of applied N (e.g. 120 and 240 kg N ha^{-1} a^{-1}) aerial tillering was negligible.

From the point of view of persistence, the contribution of aerial tillers is negligible (Korte *et al.* 1987). Therefore, pasture management should not aim to stimulate aerial tiller production. The higher aerial tiller densities observed at high N levels in this trial were most likely due to some base shading occurring at these levels (Mitchell 1953; Langer 1972; Hughes & Jackson 1974) as a result of stimulated vegetative growth at high levels of N. Under conditions where base shading occurs, aerial tillering tends to be promoted (Korte *et al.* 1987; L'Huillier 1987). While aerial tiller densities (for all treatments) were low, these could have been far greater with lower levels of defoliation frequency and intensity (Tainton 1974; Korte *et al.* 1987; L'Huillier 1987).

4.3.5 Conclusions

Increasing levels of applied N increased total tiller density of perennial ryegrass. While this effect was not apparent just after establishment (October 1993), it became significantly ($P \leq 0.05$) apparent from November 1993 to September 1994. There was very little difference ($P > 0.05$) in perennial ryegrass tiller densities between the 480 and 720 kg N ha^{-1} a^{-1} application levels. The effect of increased total tiller densities with increasing levels of applied N is attributed to the high levels of grazing defoliation frequency and intensity. It is suggested that the opposite effect (i.e. low tiller densities at high levels of applied N) may occur if low levels of defoliation frequency and intensity are applied.

Applied N levels above 240 kg ha^{-1} a^{-1} promote reproductive tiller development, while levels above 600 kg ha^{-1} a^{-1} depress reproductive tiller development. In general, however, little importance can be placed on the level of reproductive tiller densities observed in this trial since their magnitude was (for all treatments) extremely low. This low magnitude was most likely a result of the high levels of grazing defoliation frequency and intensity adopted in this trial.

Increasing levels of applied N increased ($P \leq 0.05$) aerial tiller density, while at low levels of applied N (e.g. 120 and 240 kg N ha^{-1} a^{-1}) aerial tillering was negligible. The higher aerial tiller densities observed at high N levels were most likely due to some base shading (which tends to promote aerial tillering) occurring at these levels. Aerial tiller densities (for all treatments) were low and most likely due to the high levels of defoliation frequency and intensity applied.

4.4 Herbage production and quality

4.4.1 Introduction

It is well established that increased levels of applied N increase the DM yield of a pasture and its quality (especially herbage N). An objective of this study was to identify the effects of increasing levels of applied N on DM production during the establishment year, and to identify if an upper limit for DM production existed for the range of N treatments applied. Eckard (1994) observed a linear response in DM production up to 600 kg N ha^{-1} for perennial ryegrass (the upper level for his treatments). It was also an objective of this study to quantify the effects of applied N on digestibility and herbage N, and to establish whether or not upper limits for digestibility and herbage N existed for the range of N treatments applied.

4.4.2 Sampling procedure

The procedures used to estimate herbage DM production were the same as those for the grazing trial (section 3.4.2). Herbage DM production was estimated using the pasture disc meter (Bransby & Tainton 1977) by taking 50 disc meter readings (Burns *et al.* 1989) before and after grazing with sheep. Herbage DM production was thus an estimate of the DM consumed by the sheep and was calculated from the yield estimate (disc meter regression) just before sheep entered a camp, minus the residual herbage remaining when animals left the camp. The pasture disc meter was also re-calibrated at the start of each season (i.e. four times per year) and separately for each treatment (i.e. six N treatments).

For the duration of the trial, six randomly placed quadrats (25 cm X 25 cm) per plot were clipped prior to each grazing period. From the bulked sample of these a sub-sample was taken, dried in a forced draught oven at 60 °C for 48 hours, milled and stored in a deep freeze until subsequent quality analyses could be conducted. Herbage dissections were carried out on bulked samples to apportion total yield to perennial ryegrass or other (weed) species.

The *in vitro* digestibility of herbage samples was estimated from cellulase DM disappearance (CDMD) using the cellulase digestion procedure (Zacharias 1986). Herbage N was estimated using an auto-analyzer incorporating a technique based on a modification of the Kjeldahl method (Hambleton 1977). Both CDMD and herbage N were estimated for the total sward composition and not for perennial ryegrass and weed species individually. As for the grazing trial (CHAPTER 3), the objective of addressing persistency related parameters was the major priority of this study. Characterising changes in total sward quality was, therefore, deemed more appropriate than separating perennial ryegrass and weed species.

4.4.3 Data analysis

All data were subjected to analysis of variance (randomized blocks design) and LSD tests were applied to treatment means (Steel & Torrie 1981). Regression analyses were conducted on the whole year's data to establish models describing the DM yield, CDMD digestibility and herbage N responses to applied N (Steel & Torrie 1981).

4.4.4 Results and discussion

4.4.4.1 Dry matter production

Total herbage DM yields, perennial ryegrass DM yields and DM yields of weed species on a seasonal basis are presented in Table 4.2. The predicted DM yield response of perennial ryegrass for the entire year (1 October 1993 to 30 September 1994) is given in Figure 4.5.

Table 4.2 Total herbage, perennial ryegrass and weed species DM production (estimated yield removed by sheep) on a seasonal and annual basis (1 October 1993 to 30 September 1994)

Season		120	240	360	480	600	720	LSD
				(kg N $ha^{-1}a^{-1}$)				(0.05)
Early	Total	2561	1295	2384	2384	1852	2462	465
Summer	Ryegrass	2492	1251	2339	2326	1808	2433	408
(Oct/Nov)	Weeds	69	44	45	58	44	29	25
Mid	Total	1933	2167	2234	2723	2886	3155	374
Summer	Ryegrass	1548	1842	2019	2580	2680	2967	371
(Dec/Jan)	Weeds	385	325	215	143	206	188	62
Late	Total	1576	1755	1971	2425	2765	2618	478
Summer	Ryegrass	607	694	1384	2191	2497	2364	465
(Feb/Mar)	Weeds	969	1061	587	234	268	254	78
Autumn	Total	656	910	1440	1782	2110	2025	393
(Apr/May)	Ryegrass	349	718	1336	1739	2445	1972	526
	Weeds	307	192	164	43	65	53	69
Winter	Total	215	492	1184	1753	1976	1820	479
(Jun/Jul)	Ryegrass	163	405	1160	1741	1956	1808	488
	Weeds	52	87	24	12	20	12	28
Spring	Total	289	379	1204	1809	2079	2479	471
(Aug/Sep)	Ryegrass	215	300	1124	1764	2052	2439	467
	Weeds	74	79	80	45	27	40	31
Totals	Total	7230	6998	10417	12876	13668	14559	1673
(year)	Ryegrass	5374	5210	9362	12341	13438	13983	1724
	Weeds	1856	1788	1055	535	230	576	498

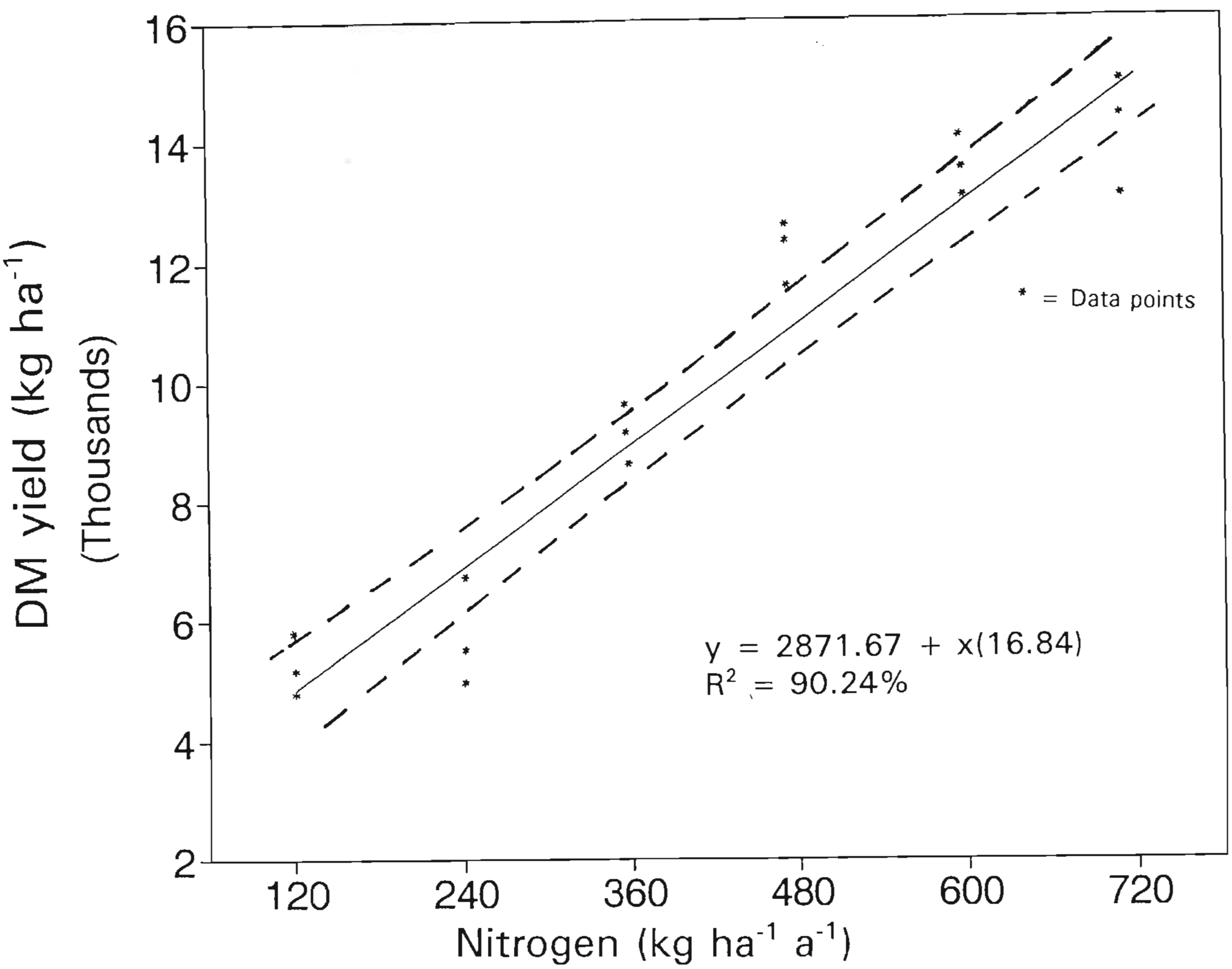


Figure 4.5 The predicted response of perennial ryegrass DM yield (y = DM yield (kg ha^{-1} a^{-1}); estimated yield removed by sheep) in relation to applied N (x = applied N (kg ha^{-1} a^{-1})) for the experimental period 1 October 1993 to 30 September 1994. Confidence intervals (95%) are represented by the broken lines.

Total DM production ranged from 6 998 (240 kg N ha^{-1} a^{-1}) to 14 559 (720 kg N ha^{-1} a^{-1}) kg ha^{-1} (Table 4.2). Generally, increasing levels of applied N increased ($P \leq 0.05$) both the total and perennial ryegrass DM yields. Conversely, however, increasing levels of applied N significantly ($P \leq 0.05$) reduced DM yields of weed species up to 480 kg N ha^{-1} a^{-1}, thereafter producing no effect ($P > 0.05$) on weed DM production.

Responses such as these (Table 4.2), where increasing levels of applied N increase DM yield, are well documented (Castle *et al.* 1965; Holliday & Wilman 1965; Davies 1971; Ball 1979; Wilman & Mares Martins 1977; Eckard 1994). What is interesting, however, is that weed DM yields decreased with increasing levels of applied N (Table 4.2). It is generally accepted that the tropical weed species (e.g. *Digitaria sanguinalis and Eragrostis curvula*) encountered in the trials (see section 3.6.3 and 4.6.3) respond very well to applied N (Tainton 1981). The reason for the observed response is perhaps related to competition. After establishment the sward was comprised mainly of perennial ryegrass. Weed species establishing after this would have exhibited lower growth rates during their establishment than the existing more erect perennial ryegrass, mainly due to shading effects by the perennial ryegrass (Harris & Thomas 1972). It is suggested that such an effect is greater at high than at low levels of applied N.

In order to establish if applied N imposed an upper limit on perennial ryegrass DM yield, data were subjected to various regression analyses to determine the 'best fit' model. Where N is applied to pasture crops, the DM yield response usually has three distinct phases (Sparrow 1979):

1) a sharply rising phase,
2) a turning point, and
3) a portion where yield no longer increases, or even slowly decreases.

Eckard (1994) comprehensively reviewed the literature and reported that many regression functions to N response curves have been established with varying degrees of success. Models have ranged from linear polynomials to non-linear functions to inverse polynomial functions. Such models are established for a given set of circumstances.

To address the objective of this section, both linear and non-linear (to test for asymptotes) functions were tested. The 'best fit' option was a linear model (Figure 4.5) described by the function $y = 2871.67 + x(16.84)$, where y is the perennial ryegrass DM yield (kg DM ha^{-1} a^{-1}) and x is the N fertilizer application level (kg N ha^{-1} a^{-1}).

This model (Figure 4.5) suggests a linear response in DM yield up to 720 kg N ha^{-1} a^{-1}, the upper limit of the N range tested. At all levels of applied N, however, DM yield was most likely lower than the potential because of the high grazing frequency and intensity programme adopted. Lower levels of defoliation frequency and intensity result in higher DM yields than high defoliation frequency and intensity (e.g. Holliday & Wilman 1965; Tainton 1974; Lambert *et al.* 1986; Togamura 1993; HFHI versus LFLI in section 3.4.4). An upper limit to DM yield may have been observed at a lower level of N (e.g. 480 kg ha^{-1} a^{-1}) if a low grazing frequency and intensity had been adopted. Holliday and Wilman (1965) reported that a linear response in DM yield occurred with increasing levels of N fertilizer (up to 470 kg N ha^{-1} a^{-1}), but only when defoliation frequencies were high (every two weeks). Eckard (1994), under sub-tropical conditions, showed a linear response to applied N up to 600 kg ha^{-1} a^{-1}, the upper level of the range tested. It is cautioned, however, that economic analyses incorporating animal production parameters should be simultaneously applied as these may preclude any DM yield based recommendations for very high levels of applied N. In addition, different defoliation frequencies and intensities need to be applied when establishing the effects of increasing levels of applied N on DM yields.

It is also cautioned that limitations apply to this model (Figure 4.5). The model was based on only one year's data, and it incorporated DM yields taken after establishment when all treatments had received equal 'pop up' dressings of N. Thus, the actual yield response to low N levels may have been less than those observed.

4.4.4.2 Herbage quality

The CDMD values for total sward composition are given in Figure 4.6, while herbage N values for the total sward composition are given in Figure 4.7. Predicted responses of total sward CDMD and herbage N to applied N are presented in Figures 4.8 and 4.9, respectively.

The CDMD ranged from 74% (at 720 kg N ha^{-1} a^{-1}) in early summer to 42% (at 120 kg N ha^{-1} a^{-1}) in autumn (Figure 4.6). Increasing levels of applied N increased ($P \leq 0.05$) CDMD in most seasons, except early summer. Generally, however, levels of applied N above 480 kg ha^{-1} a^{-1} did not produce significant ($P>0.05$) differences. Research data have consistently demonstrated that increased levels of applied N improve the digestibility of pasture crops (Vincente-Chandler *et al.* 1974; Skerman & Riveros 1990). Wilman *et al.* (1977) found that application of N reduced the proportion of plant cell wall, thereby increasing its digestibility. From these results (Figure 4.6), there is little justification in applying N levels in excess of 480 kg ha^{-1} a^{-1} to improve CDMD.

Total sward herbage N ranged from 4.4% (at 480 kg N ha^{-1} a^{-1}) in early summer to 1.5% (at 120 kg N ha^{-1} a^{-1}) in autumn (Figure 4.7). Increasing levels of applied N increased ($P \leq 0.05$) herbage N in most seasons, except in early summer. However, levels of

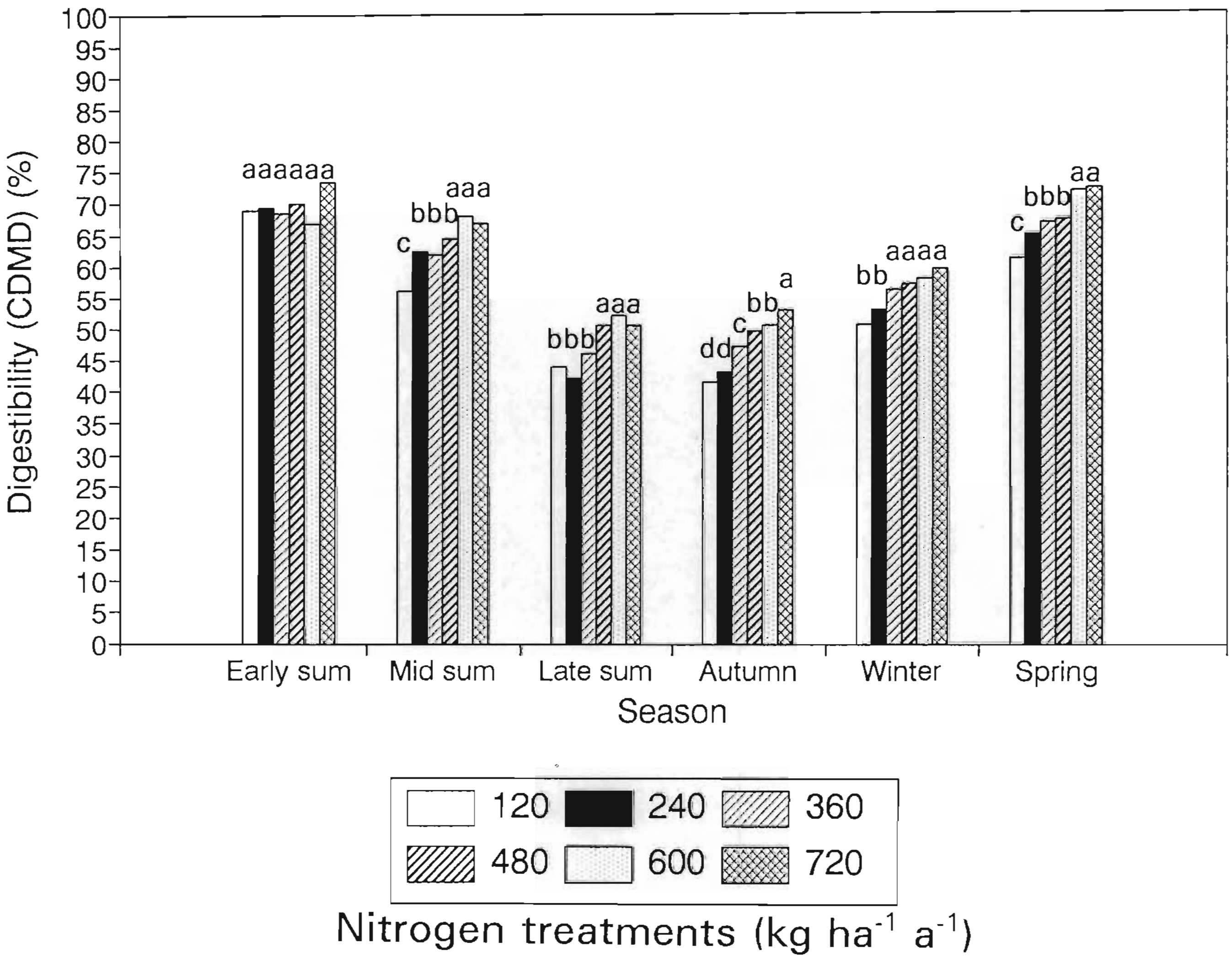


Figure 4.6 Total sward herbage digestibility (CDMD) on a seasonal basis from 1 October 1993 to 30 September 1994. Bars with letters in common are not significantly different (P>0.05).

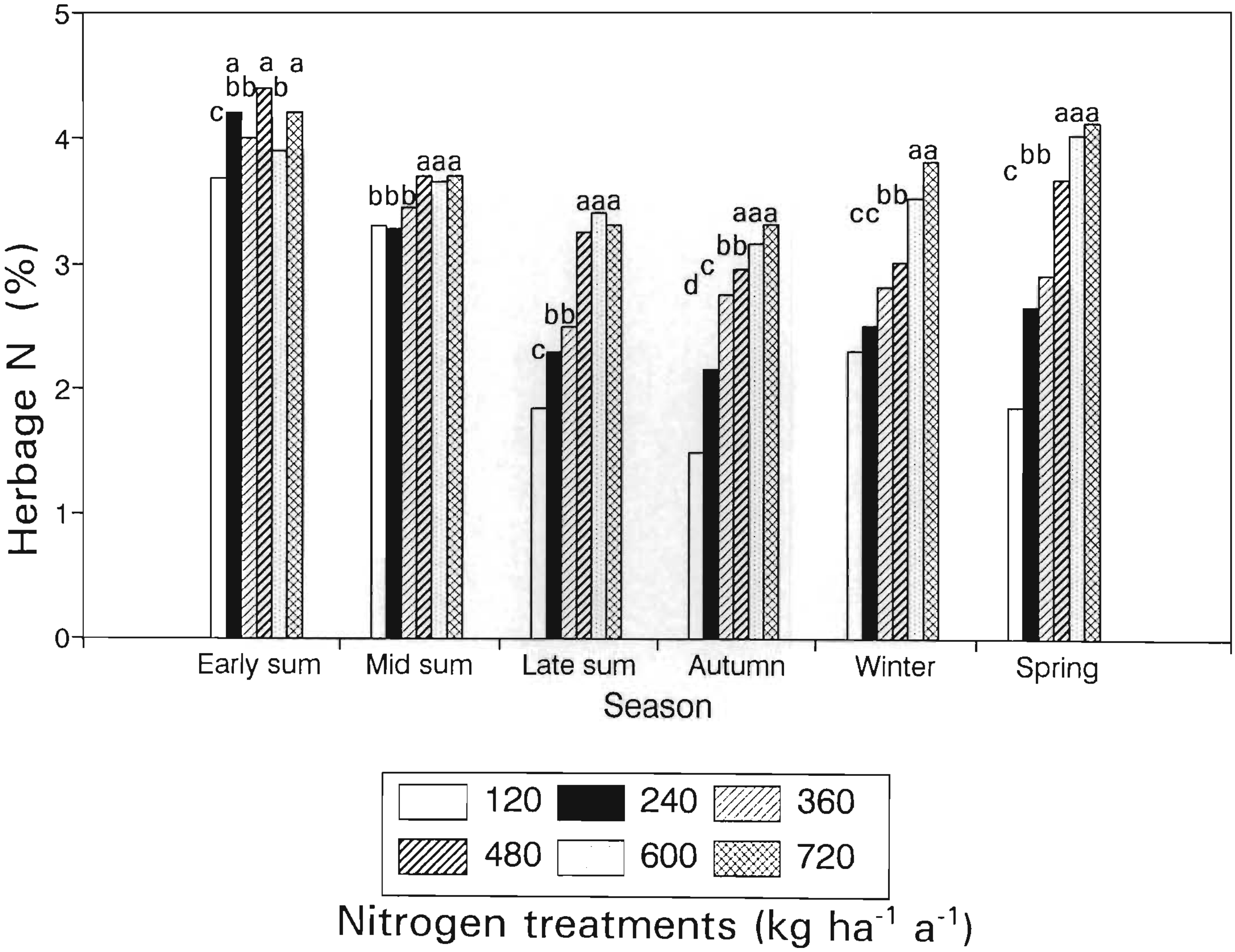


Figure 4.7 Total sward herbage N on a seasonal basis from 1 October 1993 to 30 September 1994. Bars with letters in common are not significantly different ($P>0.05$).

applied N above 480 kg ha^{-1} a^{-1} did not generally produce significant ($P>0.05$) differences. Research data have demonstrated that applying N to pastures increases the herbage N content. Frame and Hunt (1971) found the herbage N levels of perennial ryegrass to be 2.2, 2.7 and 3.4% with N applications of 100, 234 and 351 kg ha^{-1}, respectively. From these results (Figure 4.7), there is again little justification in applying N levels in excess of 480 kg ha^{-1} a^{-1} to improve the herbage N content of perennial ryegrass.

The seasonal patterns of CDMD and herbage N were similar to those established in the grazing trial (section 3.4.4.2). These levels were lowest in the late summer and autumn periods, and highest in spring and early summer (Figures 4.6 & 4.7). This may be attributed, in one instance, to the higher proportion of weed species (tropical grasses) contributing to total sward production in the late summer and autumn periods (Table 4.2), particularly at low levels of applied N. Tropical grass species (which comprised the bulk of weed species, see section 4.6.4) usually exhibit lower herbage quality than temperate species (Bredon & Stewart 1978). Also, the degree of defoliation, which was more lenient during summer than winter, may have increased the proportion of lower quality residual material in the late summer/autumn periods, relative to the spring and early summer periods (Ashford & Troelsen 1965; Togamura *et al.* 1993).

In order to predict the responses of CDMD and herbage N to applied fertilizer N, regression analyses (both linear and non-linear) were conducted.

The response of CDMD to applied N was described by the function $y = 51.57 + x(1.57 * 10^{-2})$, where y is the total sward CDMD (%) and x is the N fertilizer application level (kg N ha^{-1} a^{-1}) (Figure 4.8).

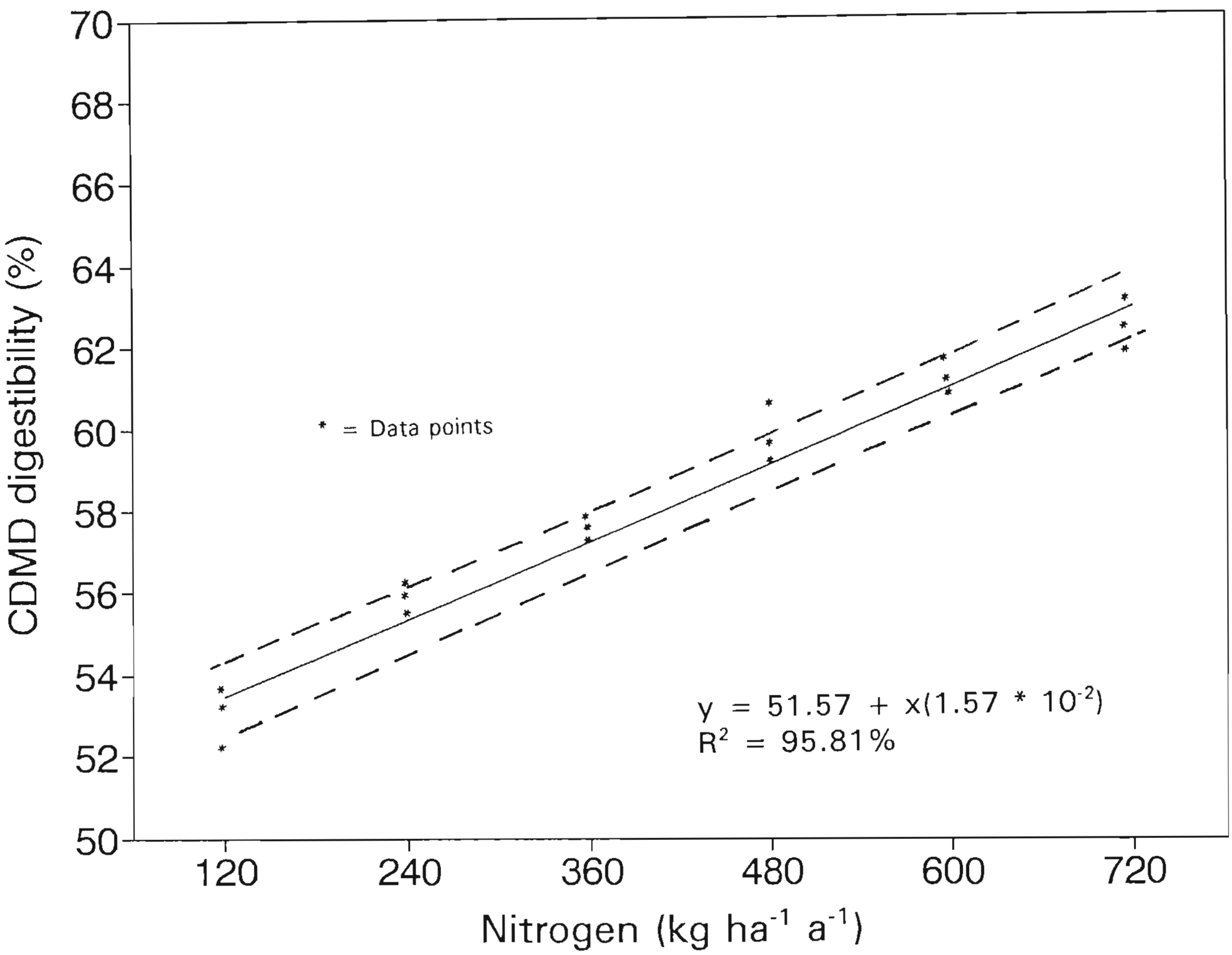


Figure 4.8 The predicted response of total sward CDMD digestibility (y = CDMD (%)) to applied N (x = applied N (kg ha^{-1} a^{-1})) for the experimental period 1 October 1993 to 30 September 1994. Confidence intervals (95%) are represented by the broken lines.

The response of herbage N to applied N was described by the function $y = 2.14 + x(2.37 * 10^{-3})$, where y is the total sward herbage N (%) and x is the N fertilizer application level (kg N ha^{-1} a^{-1}) (Figure 4.9).

These models (Figures 4.8 & 4.9) suggest linear responses in CDMD digestibility and herbage N up to 720 kg N ha^{-1} a^{-1}, the upper limit of the N range tested. It must be noted that although CDMD and herbage N increased throughout the range of N applied (up to 720 kg ha^{-1} a^{-1}), such increase was, in most cases, significant ($P \leq 0.05$) only up to the 480 kg N ha^{-1} a^{-1} (Figures 4.6 & 4.7). A review of herbage digestibility for tropical grasses (Skerman & Riveros 1990) has also indicated linear responses of increasing digestibility with increasing N. Vincente-Chandler *et al.* (1974) showed a linear response for herbage N up to 880 kg N ha^{-1} a^{-1} in tropical grasses, before the response tapered off. Frame and Hunt (1971), working under temperate conditions on perennial ryegrass, also found a linear response in herbage N up to 351 kg N ha^{-1} a^{-1}, the upper N level tested. Eckard (1994) reported a linear increase in herbage N up to 600 kg N ha^{-1} a^{-1} for perennial ryegrass under sub-tropical conditions. It may be interesting to test CDMD and herbage N parameters at applied N levels above those tested in this trial in order to identify potential upper limits that applied N may have on these parameters. Such an experiment should include animal production parameters to test if very high levels of applied N can be economically justified.

These models should, however, be interpreted with caution as the same limitations applying to the DM yield model (Figure 4.5), apply to these two models (Figures 4.8 & 4.9). They are based only on one year's data, and include herbage quality values estimated after establishment when all treatments received equal applications of 'pop up' N. Furthermore, they are not a true reflection of the CDMD and herbage N contents of perennial ryegrass as they include weed species. This fact could have

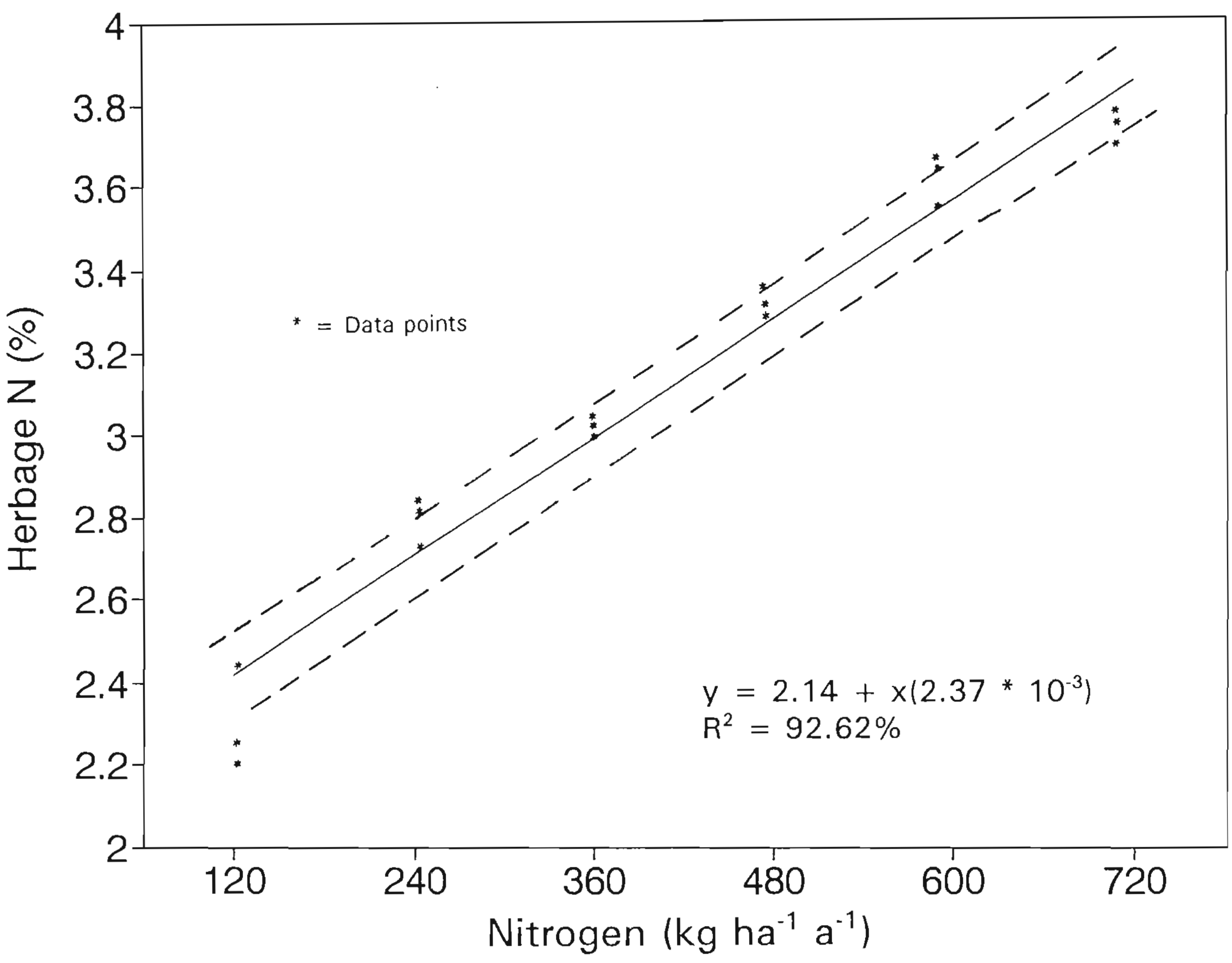


Figure 4.9 The predicted response of total sward herbage N (y = herbage N (%)) to applied N (x = applied N (kg ha^{-1} a^{-1})) for the experimental period 1 October 1993 to 30 September 1994. Confidence intervals (95%) are represented by the broken lines.

produced erroneous estimates of perennial ryegrass quality, particularly at the low levels of applied N where weed DM production was high (Table 4.2).

4.4.5 Conclusions

Increasing levels of applied N increased ($P \leq 0.05$) both total and perennial ryegrass DM yields. Conversely, however, increasing levels of applied N up to 480 kg N ha^{-1} a^{-1} significantly ($P \leq 0.05$) reduced DM yields of weed species.

A model predicting the response of perennial ryegrass DM yield to applied N suggests a linear response in DM yield up to 720 kg N ha^{-1} a^{-1}, the upper limit of the N range tested in this trial. It is suggested, however, that the model be refined further and that it include economic analyses incorporating animal production parameters, as these may preclude any DM yield-based recommendations for very high levels of applied N.

Although CDMD and herbage N increased throughout the range of N applied (up to 720 kg ha^{-1} a^{-1}), such increase was significant ($P \leq 0.05$) only up to the 480 kg N ha^{-1} a^{-1}. Prediction models for both CDMD and herbage N suggest a linear response up to 720 kg N ha^{-1} a^{-1}, the upper N level tested in this trial. These are, however, preliminary and additional experimentation, incorporating animal production parameters, is required to establish optimum economical N levels.

4.5 Perennial ryegrass vigour

4.5.1 Introduction

Much emphasis is placed on pasture management that enhances tiller production. Equally important, but less emphasised, is the maintenance of plant vigour in perennial ryegrass pastures. Ultimately, it is management geared towards the survival of tillers, rather than merely stimulating tiller numbers (although this is important), that will enhance pasture persistence. One such management variable, namely N application, may indeed influence the longevity of perennial ryegrass, but is poorly understood for South African sub-tropical conditions. This study, therefore, evaluated the effect of different levels of applied N on the vigour of perennial ryegrass. Also considered was the effect of applied N on the vigour of perennial ryegrass in different seasons, and the vigour of individual tillers.

4.5.2 Sampling procedure

Three randomly located quadrats (20 cm X 20 cm) per plot were clipped using a pair of scissors. This, in effect, provided a total of nine observations per N treatment (3 quadrats X 3 treatment replications). The criteria used in clipping the quadrats, the light proof 'boxes' used, and the duration of the observations (i.e. for two weeks) were the same as those described previously (section 3.5.2).

Over the duration of the trial (one year), a total of six etiolated growth observations were made, each during the last month of a seasonal period, namely November, January, March, May, July and September. The objective was thus to estimate perennial ryegrass vigour periodically over the year, and observe the effect of different levels of applied N on this.

4.5.3 Data analysis

The analysis approach was the same as that adopted for the grazing trial (see section 3.5.3). Logarithmically (natural logarithms) transformed data (expressed per unit area) were subjected to analysis of variance (randomized blocks design incorporating nested sub-sampling). An analysis of variance (randomized blocks design incorporating nested sub-sampling) was also conducted on tiller density data after applying a square root transformation. Least significance difference tests were applied to treatment means (Steel & Torrie 1981).

4.5.4 Results and discussion

The average total dry weight of etiolated growth occurring over a two week period expressed per unit area, for six seasons during 1993/94, is presented in Figure 4.10. This figure illustrates both transformed and untransformed treatment means.

Initially (during early summer), no significant ($P>0.05$) treatment effects were expressed (Figure 4.10). Thereafter, however, a trend emerged whereby plant vigour increased with increasing levels of applied N. Significant ($P\leq0.05$) treatment effects were observed from mid summer to spring. Interestingly, however, the top three N application levels (namely 480, 600 and 720 kg $ha^{-1}a^{-1}$) were never significantly ($P>0.05$) different from one another in any season for the duration of the trial. This suggests that, in terms of increasing plant vigour, there is little justification for applying N levels greater than 480 kg $ha^{-1}a^{-1}$.

As with the grazing trial (section 3.5.4), irrespective of treatment effects, perennial ryegrass vigour was observed to decline during the mid to late summer period. This was well illustrated for both transformed and untransformed treatment means (Figure 4.10).

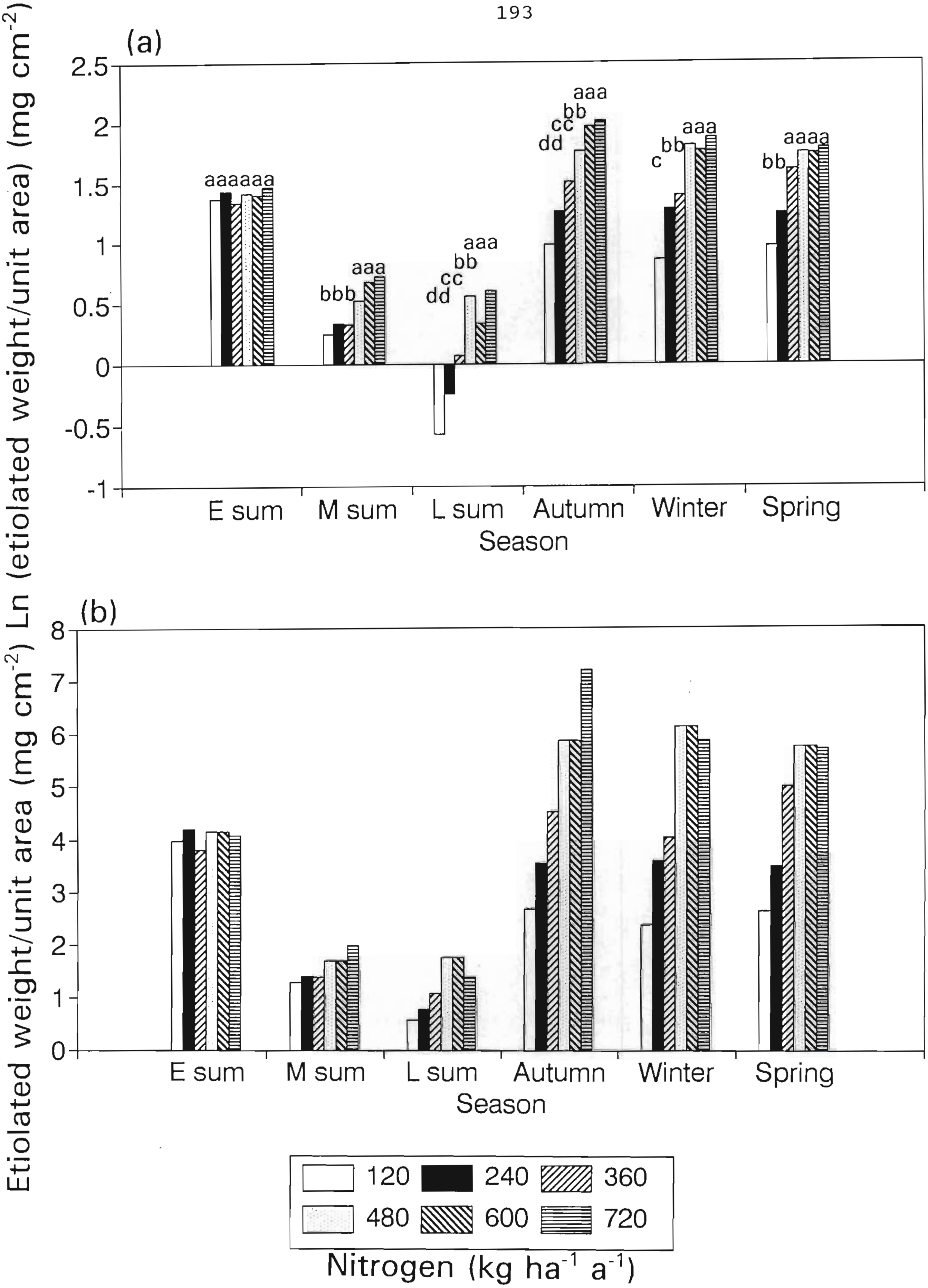


Figure 4.10 Average total etiolated dry weight per unit area (a) (natural log transformed; bars with letters in common are not significantly different (P>0.05)) and (b) (untransformed treatment means) produced by each treatment over a two week period

This may indicate that perennial ryegrass experiences a general slump in vigour during the summer months under sub-tropical conditions encountered at Ukulinga.

In order to establish whether the observed results of low etiolated weights per unit area at low levels of applied N were a result of lack of stored reserves and not a lack of meristematic growth points, additional analyses were conducted with the data. The average dry etiolated weight of tillers was plotted against the average tiller density for six seasonal observations. These results are presented in Figure 4.11. Evident is that there were treatment differences in both tiller density and average tiller weights.

Initially (early and mid summer), no significant ($P>0.05$) treatment differences were observed, presumably because treatment effects had not yet expressed themselves at this stage of the trial (Figure 4.11). Thereafter, however, significant ($P\leq0.05$) differences were observed in both tiller density and average tiller weight. Treatment trends were such that increased levels of applied N resulted in a general increase in tiller density, and a decrease in average tiller weights. These results suggest that increasing levels of applied N increase the number of active growth points. However, the individual contribution of these to etiolated growth was small. This would imply that individual tiller vigour is low at high N application rates. The opposite effect for high N rates was noted when etiolated weight was expressed per unit area (Figure 4.10), where high N rates produced high etiolated weights per unit area. This was obviously the result of a very large number of tillers each contributing small amounts of etiolated growth. In summarizing these results, it is suggested that increased levels of applied N increases the number of tillers contributing to etiolated growth, but simultaneously reduces individual tiller vigour.

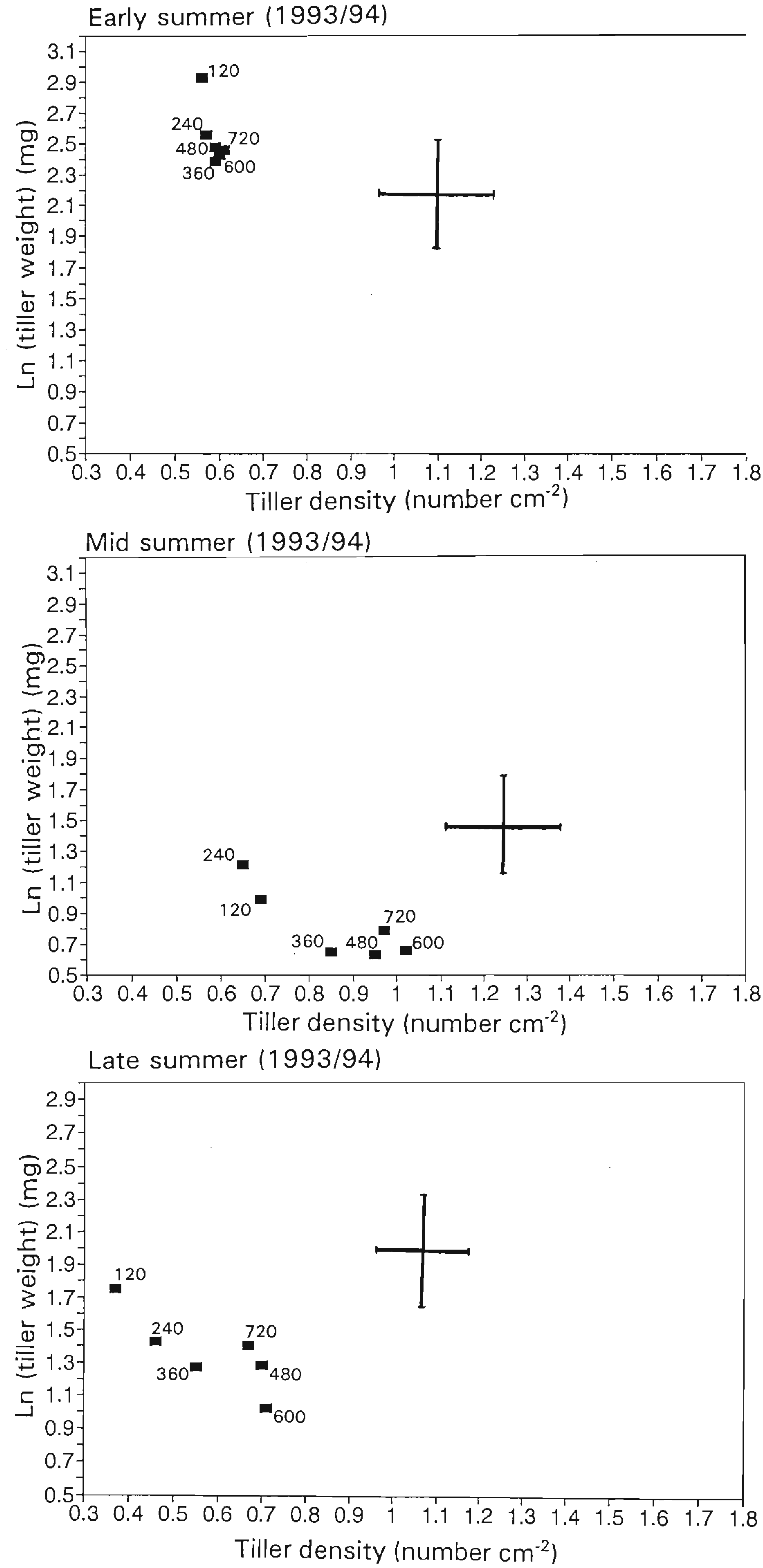
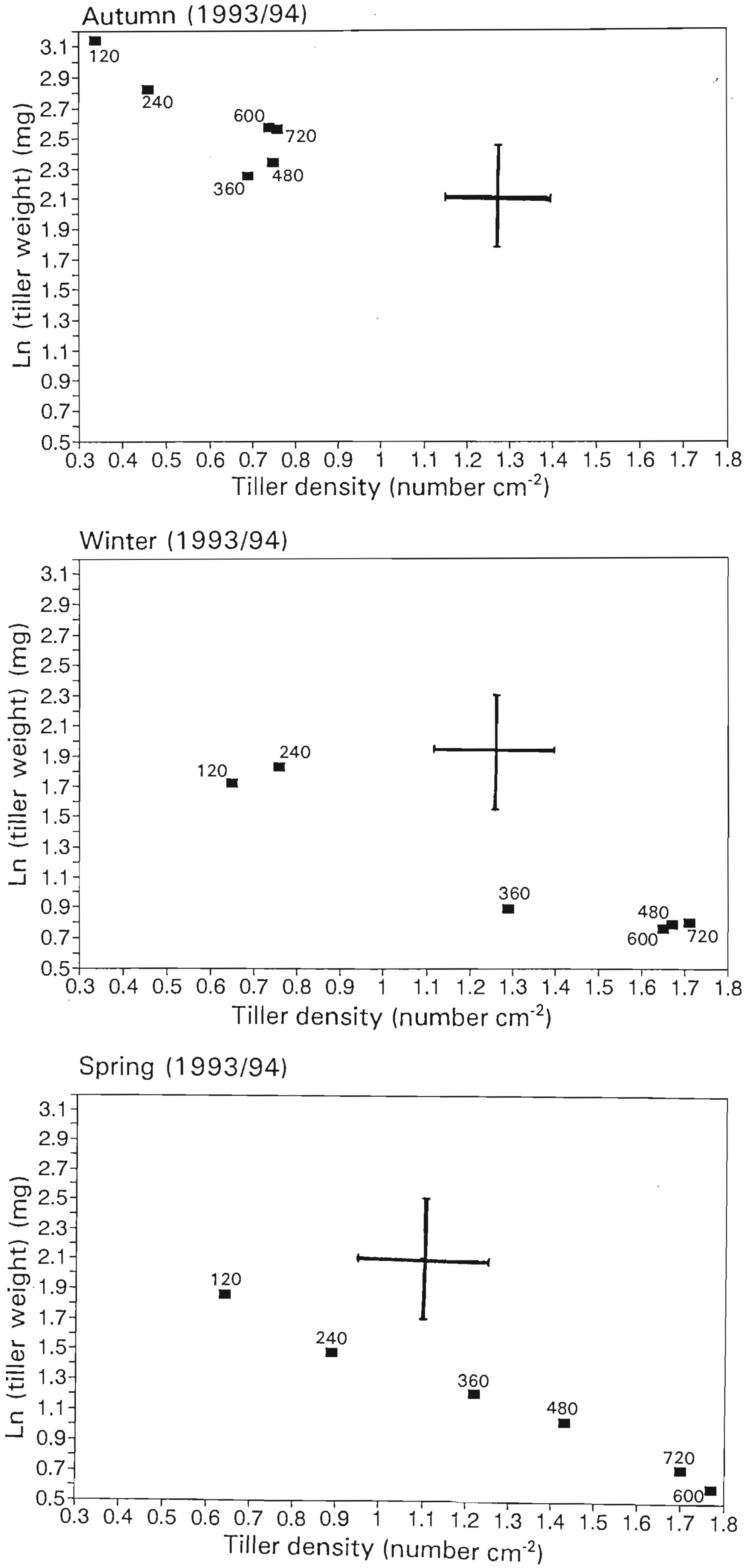


Figure 4.11 Average total etiolated tiller dry weight (natural log transformed) versus average tiller density (number per unit area and square root transformed) for 2 weeks of regrowth, and for six seasonal periods during 1993/94. The LSD


Autumn (1993/94)
Ln (tiller weight) (mg)
Tiller density (number cm-2)
120
240
600
720
480
360
Winter (1993/94)
Ln (tiller weight) (mg)
Tiller density (number cm-2)
120
240
360
480
600
720
Spring (1993/94)
Ln (tiller weight) (mg)
Tiller density (number cm-2)
120
240
360
480
720
600

Hughes and Jackson (1974) reported a decline in the persistency of perennial ryegrass when carbohydrate reserves were depleted and root growth reduced as a result of severe grazing. This observation was particularly evident with high N applications. In order to see if such an effect will occur on perennial ryegrass under sub-tropical conditions, it will be necessary to observe the pasture for an additional year. Hughes and Jackson (1974) also contended that under-utilization creates excessive shading, and together with high N inputs, encourages marked basal elongation and development of aerial tillers. Under such conditions, rapid internode elongation elevates viable tiller sites to vulnerable positions. This, however, was not considered a potential problem on the current trial because the grazing defoliation programme was one of high frequency and high intensity defoliation. It is believed that these two contrasting situations (under and over-utilization) could ultimately reduce the development and viability of basal tiller buds.

4.5.5 Conclusions

Two aspects concerning the vigour of perennial ryegrass in response to applied N have been highlighted:

1) plant vigour, as indexed by etiolated growth per unit area, increased with increasing levels of applied N. However, there appeared to be no justification for applying N at rates above 480 kg ha^{-1} a^{-1} to enhance plant vigour; and
2) increasing levels of applied N increased tiller density, but reduced individual tiller vigour. In terms of production per unit area (plant vigour) at high levels of applied N, however, the effect of reduced tiller vigour was compensated for by the high tiller density (i.e. a large number of tillers, each contributing to growth).

Irrespective of treatment effects, vigour in perennial ryegrass under sub-tropical conditions during the establishment year declines during mid to late summer. It is suggested that this trend is inherent in perennial ryegrass under sub-tropical conditions.

The long-term effects of applied N on perennial ryegrass vigour still require monitoring.

4.6 Weed invasion

4.6.1 Introduction

A major problem experienced by pasture managers under the sub-tropical conditions of South Africa, is that tropical grass species invade perennial ryegrass pastures. The effect of grazing management on weed encroachment into perennial ryegrass has received attention (section 3.6, CHAPTER 3). What requires elucidation, however, is the effect applied N might have on a perennial ryegrass pasture being invaded by weed species.

This study examines the effect of applying different levels of N to a uniformly established perennial ryegrass pasture. The study also allows quantification of the effects of applied N on weed encroachment in different seasons of the year.

4.6.2 Sampling procedure

4.6.2.1 Destructive sampling

To ascertain the contribution tillers of weed species were making to the total sward tiller density, a destructive sampling technique was adopted which coincided with the procedure used to estimate perennial ryegrass tiller density (section 4.3.2). The weed tiller density was estimated in ten randomly located cores (10 cm diameter) per plot. These cores were then taken to the laboratory for separation into perennial ryegrass (to achieve the objectives of section 4.3) and other species (weeds). This procedure was conducted monthly for the duration of the trial (i.e. 12 observations).

4.6.2.2. Non-destructive sampling

To identify the relative frequencies of weeds and perennial ryegrass making up the total sward, use was also made of a non-destructive sampling technique (section 3.6.2.2). This procedure was adopted during the last month of each seasonal period for the duration of the trial, namely: November, January, March, May, July and September.

4.6.3 Data analysis

A square-root transformation was applied to normalise weed tiller density data for analysis of variance (Steel & Torrie 1981). The perennial ryegrass tiller density and relative frequency data sets, however, did not require transformation. Data were then subjected to analysis of variance (randomised blocks design incorporating nested sub-sampling). Least significance difference tests were applied to treatment means (Steel & Torrie 1981).

4.6.4 Results and discussion

The same weed species were encountered during this study as those from the grazing trial, and for the purposes of analyses all weed species were grouped together (section 3.6.3).

Weed tiller densities for 12 months during 1993/94 are presented in Figure 4.12, while the relative proportion (%) of weed tillers to total sward tiller density is given in Table 4.3. The relative frequency of perennial ryegrass and weed species for six seasonal periods during 1993/94 is given in Figure 4.13, while the average relative frequency of perennial ryegrass and weed species for the whole year is given in Figure 4.14.

Weed tiller densities ranged from 50 tillers m^{-2} (at 360 kg N ha^{-1} a^{-1}) during November 1993, to 2 400 tillers m^{-2} (at 120 kg N ha^{-1} a^{-1}) (Figure 4.12) during February 1994. Increasing levels of applied N suppressed weed tiller densities ($P \leq 0.05$), especially at high levels (> 360 kg N ha^{-1} a^{-1}). Applied N in the range of

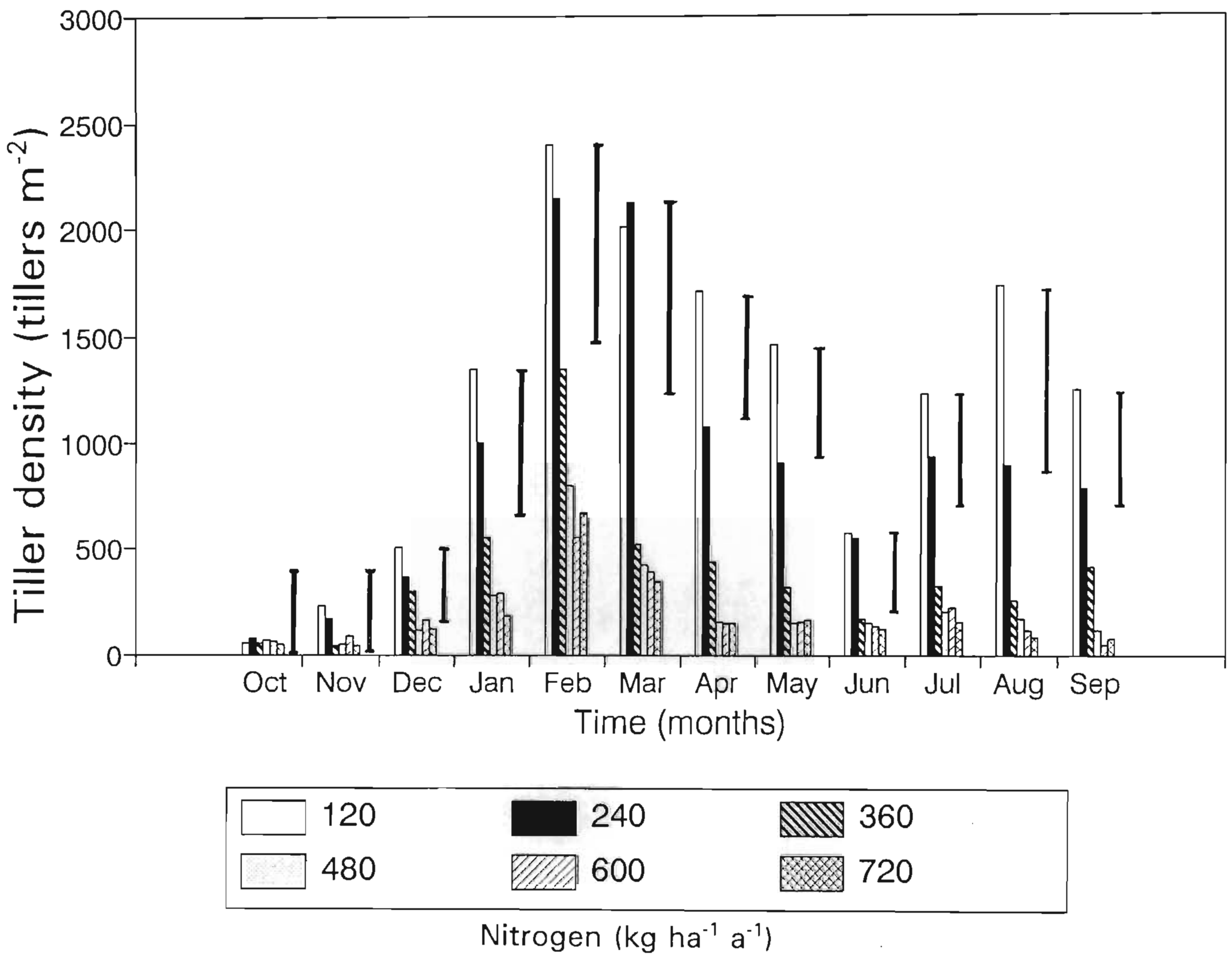


Figure 4.12 The effect of applied N on weed species tiller density. Vertical bars indicate the LSD (P=0.05) level.

Table 4.3 The proportional contribution (%) of weed species tiller density to total sward tiller density

	Treatments (kg N $ha^{-1}a^{-1}$)					
	120	240	360	480	600	720
	Proportional contribution (%)					
Oct	1	1	1	1	1	1
Nov	3	2	1	0	1	0
Dec	7	5	3	1	1	1
Jan	24	21	7	3	4	2
Feb	34	36	18	9	6	8
Mar	34	36	6	4	4	4
Apr	33	19	5	1	1	1
May	24	13	4	2	2	2
Jun	11	10	2	2	1	1
Jul	16	11	2	1	1	1
Aug	21	9	2	1	1	0
Sep	17	9	4	1	0	1

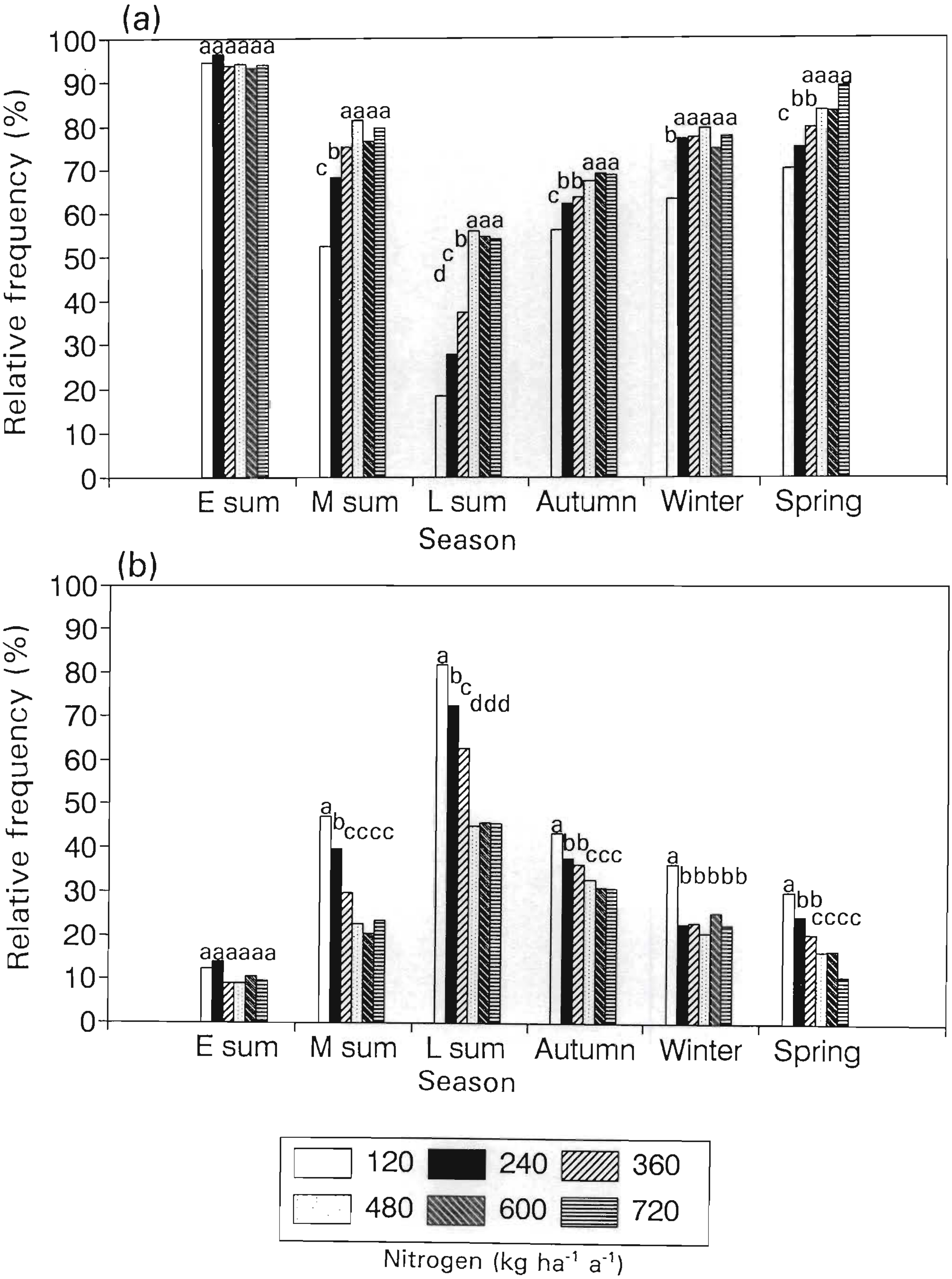


Figure 4.13 The effect of applied N on (a) the relative frequency of perennial ryegrass, and (b) the relative frequency of weed species. Bars with letters in common are not significantly different (P>0.05).

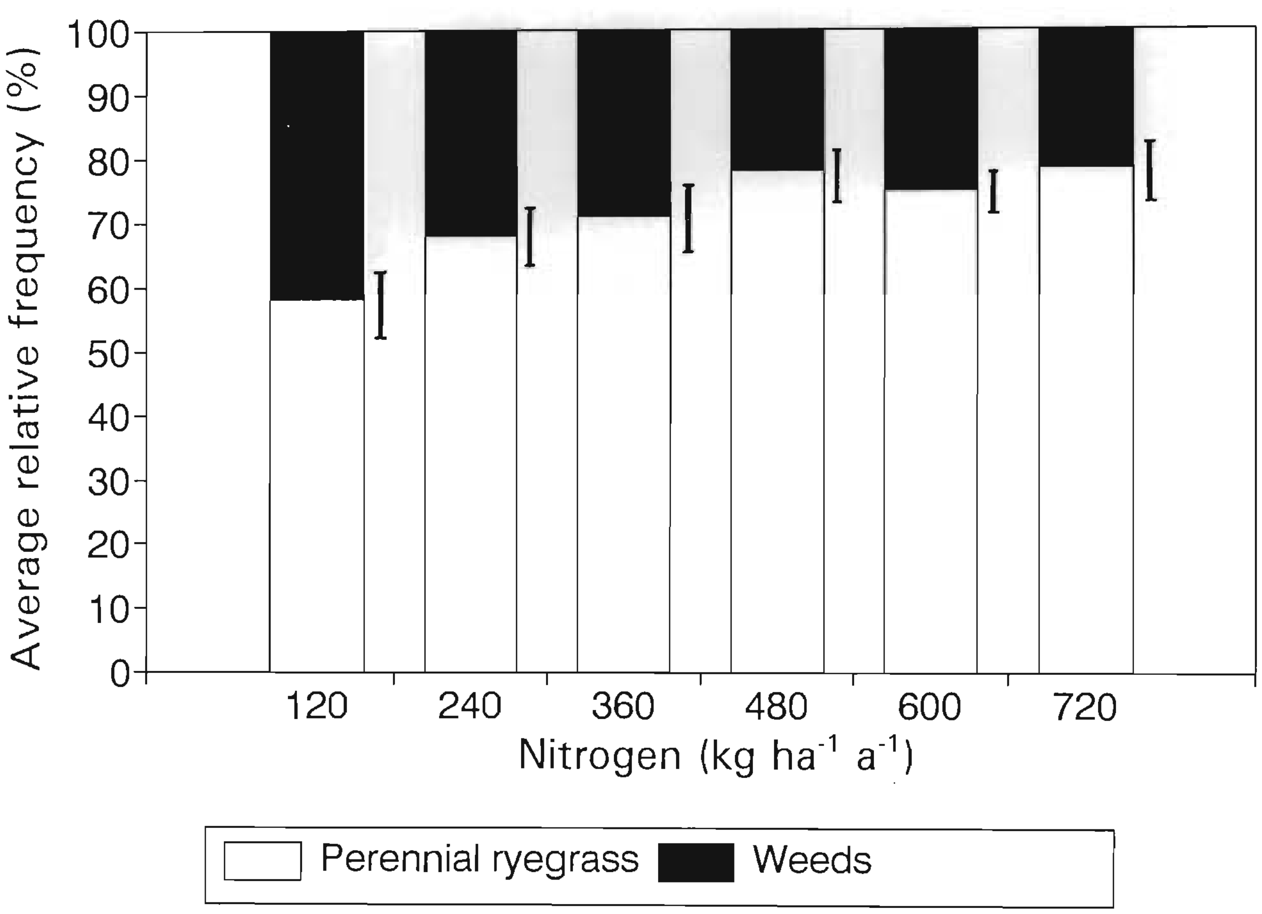


Figure 4.14 The effect of applied N on the average (six seasonal observations) relative frequency of perennial ryegrass and weed species. Standard error of each mean indicated by the vertical bars.

360 to 720 kg ha^{-1} a^{-1}, however, produced no significant ($P>0.05$) treatment effects (Figure 4.12).

The contribution of weed tillers to total sward tiller density in the 120 and 240 kg N ha^{-1} a^{-1} treatments was distinctly greater than in the other treatments, particularly between December 1993 and August 1994 (Table 4.3). For the 120 kg N ha^{-1} a^{-1} treatment, weed tiller density ranged from 7 to 34% of the total sward density during this period, and from 5 to 36% for the 240 kg N ha^{-1} a^{-1} treatment. For all other treatments, weed tiller density never exceeded 9% of the total sward tiller density, with the exception of the 360 kg N ha^{-1} a^{-1} treatment (18%) in February 1994 (Table 4.3).

Similar trends were observed for data on the relative frequency of weeds. These ranged from 9% (at 360 kg N ha^{-1} a^{-1}) during early summer to 82% (at 120 kg N ha^{-1} a^{-1}) during late summer (Figure 4.13(b)). While increasing levels of applied N suppressed the relative frequency of weed species ($P\leq0.05$), there were no significant ($P>0.05$) differences for N levels above 360 kg ha^{-1} a^{-1} (Figure 4.13(b)). The average frequency of perennial ryegrass and weed species for all observations (Figure 4.14) illustrates that very little difference in weed suppression exists at N levels above 360 kg ha^{-1} a^{-1}. All these data suggest, therefore, that there is little justification for applying N at levels in excess of 360 kg ha^{-1} a^{-1}, if the primary concern is maintaining a relatively weed free perennial ryegrass pasture. Obviously, such a view should be tested for an additional year to observe if such trends continue. Given the current level of weed infestation in the 120 and 240 kg N ha^{-1} a^{-1} treatments, however, it is envisaged that these treatments are unlikely to improve during the course of a second year.

Irrespective of treatment effects, the seasonal trend was such that high weed tiller densities were observed over the mid summer

(December) to autumn (May) period (Figure 4.12(b)). These data are supported by the relative frequency of weed species, where the highest frequency also occurred over the mid summer to autumn period (Figure 4.13(b)). This response most likely coincides with the active growth season (i.e. summer) (Gibbs Russell *et al.* 1990; Fulkerson *et al.* 1993) of the majority of the tropical weed species encountered on the trial site (e.g. *Digitaria sanguinalis, Eleusine indica, Eragrostis curvula, Paspalum distichum* and *Sporobolus africanus*). It is suggested, therefore, that general pasture management principles (such as adopting longer rest periods, particularly during summer) should be considered to minimize the incidence of weed invasion by keeping perennial ryegrass in a more competitive state than invading weed species.

It is also suggested that, although both perennial ryegrass and tropical grass species respond to increased fertility, particularly increased N, the extent of N response is less for tropical invading species. This would be particularly true after establishment when the pasture is presumably a uniform stand of perennial ryegrass and potential invading species must, therefore, compete against established perennial ryegrass plants. Harris and Thomas (1972) reported that invading weed species exhibit lower growth rates during their establishment than the existing more erect perennial ryegrass, mainly due to shading effects by the perennial ryegrass. The application of increasing levels of N presumably speeds up the recovery of a high leaf-area index after a defoliation, making perennial ryegrass more competitive against potential invading species at higher levels of N than at low levels of N.

4.6.5 Conclusions

Increasing levels of applied N reduces weed tiller densities. However, the data suggest that there is little justification for applying N at levels in excess of 360 kg ha^{-1} a^{-1}, if the primary concern is maintaining a relatively weed-free perennial ryegrass pasture. Such a view, however, requires further testing and the incorporation of different grazing regimes.

The seasonal trend in weed occurrence was such that high weed tiller densities and high frequencies were observed over the mid summer (December) to autumn (May) period. General pasture management principles (such as adopting longer rest periods) should, therefore, be considered during such times to minimize the incidence of weed invasion.

4.7 Root Development

4.7.1 Introduction

It has already been acknowledged that reduced persistence in perennial ryegrass may be linked to poor root development (Fulkerson *et al.* 1993). In this regard, Steen (1984) reported that the application of N may well influence root development negatively, presumably by encouraging vegetative growth at the expense of root development. Since no data are available for South African sub-tropical conditions on the effects of N application on perennial ryegrass root development, this study is viewed as useful in terms of gaining such knowledge.

The objective of this experiment was, therefore, to explore the effect of increasing N levels on the size of the root system of perennial ryegrass after having applied N for a full year.

4.7.2 Sampling procedure

For details on root data collection see CHAPTER 3, section 3.7.2. Six randomly placed core samples were taken per plot (i.e. 18 samples per treatment). Root sampling was conducted on one occasion only, in September 1994.

4.7.3 Data analysis

After transformation (natural logarithmic) to normalize variables, data were subjected to analysis of variance (randomized blocks design incorporating nested sub-sampling) (Steel & Torrie 1981). Least significance difference tests were applied to treatment means.

4.7.4 Results and discussion

Weights of root OM per unit volume of soil for four soil depth categories are presented for transformed and untransformed treatment means (Figure 4.15). Relative amounts of root OM occurring in each soil depth category for the September 1994 sampling period is given (Table 4.4). Immediately apparent (for transformed and untransformed means), is that there was a general increase in root OM with increasing levels of N up to 600 kg ha^{-1} (Figure 4.15). This increase was particularly evident for the 0 - 5 cm soil depth category, where root development at N levels in the range of 360 to 720 kg ha^{-1} was significantly ($P \leq 0.05$) greater than at the 120 kg N ha^{-1} application level, and at 600 N kg ha^{-1} was significantly ($P \leq 0.05$) greater than at 240 kg N ha^{-1}. This increase was less evident in the 0 - 20 cm soil depth category where N applications in the range of 240 to 720 kg ha^{-1} were significantly ($P \leq 0.05$) greater than the 120 kg ha^{-1} application level.

Although there was a slight tapering off effect of root OM in both the 0 - 5 and 0 - 20 cm soil depth categories at the 720 kg N ha^{-1} application level (Figure 4.15), this was not statistically significant ($P>0.05$). To establish if high levels of N do indeed reduce root OM, will require further investigation.

There was no apparent pattern in the 5 - 10 cm soil depth category. However, there was a general decrease in root OM in the 10 - 20 cm soil depth category with increasing levels of N, with the exception of the 240 kg N ha^{-1} treatment (Figure 4.15). Although this pattern was not significant ($P>0.05$) it may suggest that increased levels of applied N inhibit root development at deeper levels (10 - 20 cm) within the soil category (Table 4.4). Further research in this regard, however, is required.

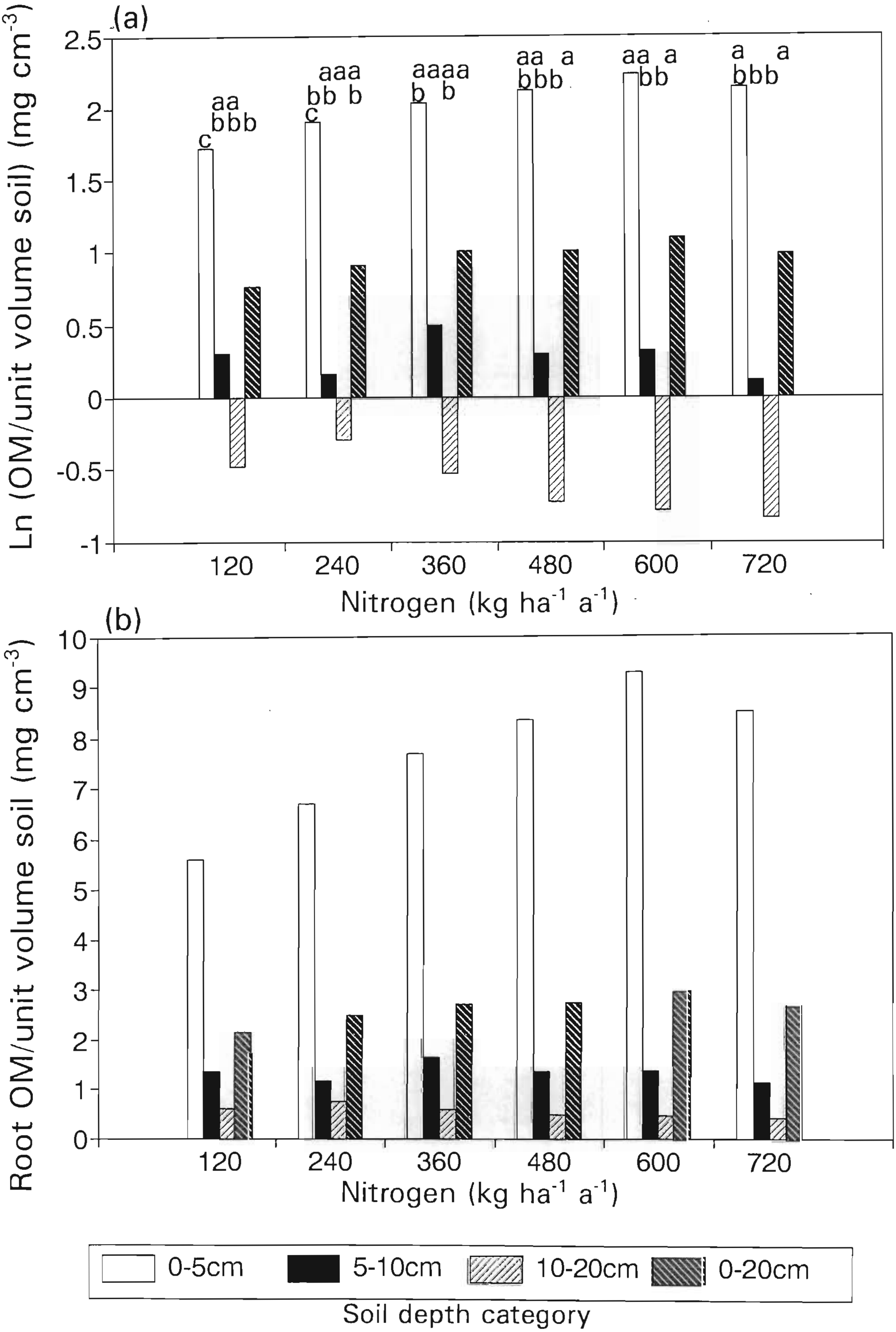


Figure 4.15 Weight of root OM per unit volume of soil (a) natural log transformed (bars with letters in common (within the same depth category) are not significantly different (P>0.05), and (b) untransformed, as assessed in September 1994 for

Table 4.4 Relative amounts (%) of root OM for each soil depth category

Sampling period	Soil depth category (cm)	Treatment ($kg\ N\ ha^{-1}$)					
		120	240	360	480	600	720
		Relative amount (%)					
September 1994	0 - 5	68	72	73	78	80	81
	5 - 10	17	13	16	13	12	11
	10 - 20	15	15	11	9	8	8
	0 - 20	100	100	100	100	100	100

The distribution of perennial ryegrass roots at varying soil depths was such that, of the total root mass sampled, the bulk (68 to 81%) occurred in the top 5 cm of the soil (Table 4.4). Increasing levels of applied N produced an increase in the proportion of roots in the top 5 cm of the soil, but at a decreasing rate. Such a condition suggests that high levels of applied N to perennial ryegrass may limit rooting depth by encouraging a greater root proportion in the upper soil level. As suggested in the discussion for root data on the grazing trial (section 3.7.4), such results would serve to emphasize the importance of frequent light irrigation scheduling.

On the other hand, this high level of root OM per unit volume of soil observed in the top 5 cm of soil (Figure 4.15) and the corresponding high proportion of root mass at this level (Table 4.4), may have coincided with the high spring tiller densities noted for the high N rates (section 4.3). In perennial ryegrass, roots were found to be produced from tiller bases in increasing numbers through late winter and early spring. Thereafter, root production decreased sharply during summer (Garwood 1967). Garwood (1969) found that the spring peak in tiller density coincided with maximum production of new roots.

In the 5 - 10 cm soil depth category, root mass ranged from a high of 17% (120 kg N ha^{-1}) to a low of 11% (720 kg N ha^{-1}) (Table 4.4). The general trend was such that root mass in this category (5 - 10 cm) decreased with increasing levels of applied N. The same trend was observed for the 10 - 20 cm depth category, where root mass decreased from a high of 15% (120 kg N ha^{-1}) to a low of 8% (for both the 600 and 720 kg N ha^{-1} application rates). These results indeed indicate that applied N (at high levels, e.g. 480 to 720 kg ha^{-1}) may inhibit deep root systems in perennial ryegrass. Such an hypothesis would, however, require further testing.

4.7.5 Conclusions

Results suggest that increasing levels of applied N (up to 600 kg ha^{-1}) increase the root OM per unit volume of soil in the top 5 cm of the soil, while a corresponding decrease in root OM per unit volume of soil is observed in the 10 - 20 cm soil depth category.

Although the evidence from the trial is inconclusive as far as rooting depth is concerned, indications are that high levels of applied N stimulate root development in the upper soil (0 - 5 cm) at the expense of root development at depth (5 - 10 and 10 - 20 cm).

As observed with the grazing trial, perennial ryegrass is extremely shallow rooted, with approximately 75% of the root mass occurring in the top 5 cm of the soil. This stresses the need to pay careful attention to irrigation scheduling.

CHAPTER 5

GENERAL DISCUSSION AND CONCLUSIONS

Lolium perenne L. (perennial ryegrass) under sub-tropical conditions in South Africa has gained a reputation for lacking persistence. The absence of objective research on how to manage this species locally has added to this problem. The major objective of this project was, therefore, to highlight management options, particularly with respect to grazing, which will help enhance the longevity of perennial ryegrass pastures under sub-tropical conditions in South Africa. This objective was addressed by:

1) reviewing current management practices applied to perennial ryegrass in KwaZulu-Natal;
2) conducting a detailed two-year field study of the effects of grazing defoliation frequency (HF, MF and LF = high, medium and low frequency, respectively) and intensity (HI, MI and LI = high, medium and low intensity, respectively), rotationally applied and with one continuous grazing treatment (CG), on parameters linked to persistency; and
3) conducting a one-year field study of the effects of different levels of applied N on various parameters linked to the persistence of the pasture.

In highlighting management options to help enhance pasture longevity, the study has also provided an understanding of the mechanisms allowing perennial ryegrass to respond to management under sub-tropical conditions.

The objectives of this chapter are to:

1) provide a discussion and the conclusions derived from the results of this project;

2) outline a management model for perennial ryegrass under sub-tropical conditions, based on both the findings of this project and the literature reviewed; and
3) outline future research directions for perennial ryegrass under sub-tropical conditions.

The current management practices applied to perennial ryegrass in KwaZulu-Natal were characterized by means of a mail survey. This study provided valuable insight into some of the reasons for the success, and conversely, the failure of perennial ryegrass systems under sub-tropical conditions in KwaZulu-Natal.

Cultivation of perennial ryegrass in KwaZulu-Natal is largely restricted by excessively high temperatures to Bioclimatic regions 3 (Mist Belt) and 4 (Highland Sourveld). Other areas in KwaZulu-Natal in which perennial ryegrass is used are Bioclimatic regions 5 (Montane), 6 (Upland (moist)), 7 (Riverine) and 8 (Upland (drier)). However, the cultivation of perennial ryegrass in these Bioclimatic regions (5, 6, 7, and 8) is less popular than in Bioclimatic regions 3 and 4. Careful defoliation and irrigation management has ensured the success of perennial ryegrass in Bioclimatic group 7 (which experiences high summer temperatures, e.g. mean annual temperatures between 17 to 22 °C), although there were only two growers in this region who responded to the survey.

The most popular season for establishing perennial ryegrass (as pure or clover-based stands) in KwaZulu-Natal is autumn rather than spring, presumably to avoid weed infestation which commonly occurs in spring-established pastures (Booysen 1981), and to avoid exposing young developing plants to extreme early summer temperatures.

Most growers in KwaZulu-Natal plant perennial ryegrass in association with clover. In addition, it appears that farmers are more confident in planting larger areas when this species is associated with clover. A very conservative estimate shows that 853 ha are currently under perennial ryegrass clover-based pastures in KwaZulu-Natal, while 295 are under pure stands of perennial ryegrass.

Most farmers report a production decline from perennial ryegrass pastures (as pure or clover-based stands) with time. The majority of farmers growing perennial ryegrass (as pure or clover-based stands), therefore, implement pasture renovation after two (pure stands) to three years (clover-based stands) (sod-seeding being the most popular option), and it is suggested that this may allow an additional year's production from the pasture before re-establishment is required. The potential benefits of pasture renovation as a means of enhancing pasture longevity should, however, be researched so that more specific practical advice can be generated on this. Overall, these results suggest that pastures containing clover have a better survival chance than those without clover. This observation is also supported by data on the frequency of complete re-establishment. Of the farmers planting pure stands of perennial ryegrass, most re-establish after three years. Compared with this, the greatest proportion of farmers planting perennial ryegrass with clover re-establish their pastures after four years. Again, the potential advantages of establishing perennial ryegrass with clover as a means of enhancing pasture longevity still require quantification under formal research conditions in this environment.

The greatest use of perennial ryegrass (as pure or clover-based stands) in KwaZulu-Natal is for dairy, followed by fat lamb and beef. With an improvement in the knowledge on how to manage perennial ryegrass under sub-tropical conditions, it is believed that this species will gain in popularity for use in fat lamb and beef production systems.

It was observed that the majority of farmers only graze their perennial ryegrass (as pure or clover-based stands), while a small proportion defoliate their pastures by both cutting and grazing. Cutting as a means of pasture utilization was positively correlated with pasture longevity, although not significantly ($P>0.05$) so. The potential benefits of mechanical defoliation, incorporated within the grazing system, in enhancing the longevity of such pastures require elucidation through research under sub-tropical conditions.

Dry matter yield estimates made by farmers for the first, second and third year of a pure stand of perennial ryegrass ranged from 14.8 to 13.5 to 12.3 t DM ha^{-1} a^{-1}, respectively. Yields of perennial ryegrass with clover ranged from 13.5 to 11.8 to 11.0 t DM ha^{-1} a^{-1}, respectively. Although these downward trends are not as drastic as expected, farmers are generally in support of the idea of re-establishing their pastures biennially, provided the DM yield decline in year two is not too great.

The field work conducted at Ukulinga showed that for the best grazing defoliation treatments, total (perennial ryegrass and weeds) DM yields ranged from 18.8 (LFHI) to 18.1 t ha^{-1} a^{-1} (LFLI) for the first and second year, respectively. For the worst grazing defoliation treatments, total DM yields ranged from 15.7 (CG) to 9.9 t ha^{-1} a^{-1} (CG) for the first and second year, respectively. In respect of DM production, there is little justification in employing very frequent defoliation. Low defoliation frequencies (e.g. 21, 28 and 35 days during summer, spring/autumn and winter, respectively) led to higher yields of perennial ryegrass during both years under sub-tropical conditions at Ukulinga, than did high defoliation frequencies (e.g. 7, 14 and 21 days during summer, spring/autumn and winter, respectively). This result is supported by research on perennial ryegrass pastures under temperate conditions (Holliday & Wilman 1965; Motazendian & Sharrow 1986). In addition, high grazing frequency tended to promote a higher level of weed production, particularly during the second year, than low grazing frequency. This has also been observed for perennial ryegrass pastures in temperate environments (Harris & Thomas 1972). Interestingly, grazing defoliation intensity did not appear to influence DM production. This was in contrast to research on perennial ryegrass under temperate conditions where low defoliation intensities have been observed to increase DM production (Tainton 1974, Lambert *et al.* 1986; Lowe & Bowdler 1988; Togamura *et al.* 1993).

Increasing levels of applied N increased yields of both the total sward and the perennial ryegrass. Conversely, however, increasing levels of applied N up to 480 kg N ha^{-1} a^{-1} reduced DM yields of weed species. A model predicting the response of perennial ryegrass DM yield to applied N suggests a linear response up to 720 kg N ha^{-1} a^{-1}, the upper limit of the N range tested. It is suggested, however, that this model be tested further and that it should include economic analyses incorporating animal production parameters, as these may preclude any DM yield based recommendations for very high levels of applied N.

The seasonal DM production trend for perennial ryegrass at Ukulinga was characterized by high levels of DM production during spring and autumn, and low levels during mid to late summer and winter. It is cautioned, however, that this trend may vary for different regions in South Africa, depending primarily on seasonal temperatures. Even under the temperate conditions of New Zealand, contrasting seasonal growth patterns have been observed (Stevens & Hickey 1989; Barker *et al.* 1993; Moloney *et al.* 1993).

The quality of perennial ryegrass, as indexed by cellulase dry matter disappearance (CDMD) and herbage N, followed definite seasonal trends, irrespective of the grazing defoliation or N treatments applied. The seasonal trend in quality (CDMD and herbage N) for perennial ryegrass pastures at Ukulinga (for both the grazing and N trials) was characterized by high levels during late autumn to early summer (May to October) and low levels during mid summer to early autumn (January to April). This trend of lower quality during mid summer to early autumn was most likely related to an increase in low quality residual material since all defoliation programmes were relatively more lenient (i.e. lower frequencies and intensities) at these times. In addition, the contribution of lower quality tropical weed species (Bredon & Stewart 1978) to total sward production was at its highest over mid summer to early spring.

While the low frequency and low intensity (LFLI) treatment tended to produce lower CDMD and herbage N levels than the other treatments, the differences between the levels were generally small. Overall, these levels of CDMD digestibility (49 to 77 %) and herbage N (2.1 to 4.4 %) fell within similar ranges obtained with perennial ryegrass in temperate environments (Baker & Leaver 1986; Morton *et al.* 1992; Barker *et al.* 1993; Stevens & Turner 1993). Interestingly, lower herbage quality for these pastures at Ukulinga was recorded during the second year relative to the first, presumably because of the increase in the abundance of lower quality tropical weed species (Bredon & Stewart 1978) during the second year.

Although CDMD and herbage N increased throughout the range of N applied (up to 720 kg ha^{-1} a^{-1}), such increase was significant ($P \leq 0.05$) only up to the 480 kg N ha^{-1} a^{-1} level. There is, therefore, little justification for increasing N applications above 480 kg ha^{-1} a^{-1} to improve herbage quality. This is in spite of prediction models for both CDMD and herbage N suggesting a linear response up to 720 kg N ha^{-1} a^{-1}. For temperate (Frame & Hunt 1971), sub-tropical (Eckard 1994) and tropical (Vincente-

Chandler *et al.* 1974; Skerman & Riveros 1990) environments, increasing levels of applied N have been shown to linearly increase the quality of grass species. It is recommended, however, that additional experimentation, incorporating animal production parameters, is required to establish economically optimum N application levels.

In terms of fertility management, the mail survey highlighted the following potential management options to enhance pasture survival. While high rates of N application (e.g. 350 and 250 kg N ha^{-1} a^{-1} to perennial ryegrass as pure or clover-based stands, respectively) may be important for pasture survival, a consistent distribution of the applied N is even more important for pasture survival. It is suggested that at least seven split applications of N be made to pure stands of perennial ryegrass and five to perennial ryegrass with clover. Eckard (1994) advised that 250 kg N ha^{-1} a^{-1} be applied as five top dressings to a perennial ryegrass clover-based pasture between April and October when the clover is less active than the perennial ryegrass. In practice, therefore, the less successful perennial ryegrass farmers can improve pasture survival, under sub-tropical conditions, by applying N in a number of dressings during the year (excluding perhaps periods of slow pasture re-growth, for example, during winter) at little extra cost. Such a management option, however, is likely to be successful only if soil acidity, and P and K levels are ameliorated to recommended levels.

From the N trial, applied N between 360 to 480 kg ha^{-1} a^{-1} proved to be the minimum N amount required to maintain a number of the persistency parameters measured.

In terms of maximum tiller population densities, there was little difference in density for applied N levels above 480 kg ha^{-1} a^{-1}. It is cautioned, however, that this may have been due to the high level of grazing defoliation frequency and intensity adopted for the N trial. Such a defoliation programme is known to stimulate tillering in perennial ryegrass under temperate conditions (Grant *et al.* 1981; Korte *et al.* 1982; Baker & Leaver 1986). Overall, the effect of applied N on reproductive and aerial tiller densities was, however, relatively small. Aerial tiller density, which is not considered important from the point of view of persistency (Korte *et al.* 1987), may have been higher for higher levels of N had a lenient defoliation programme been adopted.

Plant vigour as indexed by etiolated growth (dry weight per unit area) increased with increasing levels of applied N. There is, however, no justification for applying N at rates above 480 kg ha^{-1} a^{-1} to enhance plant vigour. Irrespective of N application, plant vigour in perennial ryegrass under sub-tropical conditions during the establishment year declined during mid to late summer. This decline in plant vigour during summer was also observed for both years of the grazing trial and has been noted for temperate conditions in New Zealand (Korte *et al.* 1982). It is suggested that this trend (reduced plant vigour in mid to late summer) is inherent in perennial ryegrass under sub-tropical conditions and is most likely related to the hot summer temperatures. Temperate grass species such as perennial ryegrass grow optimally at 25 °C, with growth declining at 25 to 30 °C and ceasing altogether at temperatures above 30 °C (Cooper & Tainton 1968; Vogel *et al.* 1978).

While increasing levels of applied N increased plant vigour and tiller density, it reduced individual tiller vigour. In terms of production per unit area, this effect at high levels of applied N was compensated for by large numbers of small tillers, each contributing to growth.

Grazing defoliation treatments incorporating a low frequency at both high and low intensity (LFHI and LFLI) had greater plant vigour than those incorporating both high frequency/high intensity rotational grazing and continuous grazing (HFHI and CG). This trend became apparent during the latter quarter (winter and spring) of the establishment year and continued throughout the second year. This result is supported by work conducted under sub-tropical conditions on tropical rangeland species (e.g. *Themeda triandra*) (Steinke & Booysen 1968; Hodgkinson *et al.* 1989; Daphne 1992) and on work conducted on perennial ryegrass under temperate conditions (Grant *et al.* 1981). Grazing defoliation intensity, on the other hand, appeared to have no influence on plant vigour, contrasting the findings of research conducted on perennial ryegrass under temperate conditions (Hughes & Jackson 1974; Grant *et al.* 1981).

The reduced etiolated growth observed in frequently defoliated treatments was apparently due mainly to poor growth reserves and not to a lack of active growth points. Towards the end of the second year, however, a lack of active growth points was also beginning to limit etiolated growth in the frequently defoliated treatments. Tillers from infrequently defoliated treatments (regardless of the level of grazing intensity) appeared to have greater vigour than tillers from the frequently defoliated treatments. For the sub-tropical conditions of South Africa, therefore, infrequent grazing defoliation programmes, particularly during summer, must be adopted to help enhance both plant vigour and individual tiller vigour.

Increasing levels of applied N reduced weed tiller densities. However, the data suggests that there is little justification for applying N at levels in excess of 360 kg ha^{-1} a^{-1} if the primary concern is maintaining a relatively weed-free perennial ryegrass pasture. The seasonal trend in weed occurrence was such that a high incidence of weeds was observed over the mid summer (December) to autumn (May) period. This trend was also observed for both years of the grazing trial and was most likely related to the hot summer conditions favouring the growth of weed species such as *Digitaria sanguinalis* and *Eragrostis curvula* (Gibbs Russell 1990). General pasture management practices (such as adopting longer rest periods during summer) should, therefore, be considered during such times to minimize the incidence of weed invasion. Low grazing frequency, irrespective of grazing intensity (LFHI and LFLI), proved to be more successful at reducing weed invasion than both high frequency/high intensity rotational grazing and continuous grazing (HFHI and CG). This was also shown to be the case for a perennial ryegrass cutting trial under the sub-tropical conditions of Australia (Fulkerson *et al.* 1993). On the other hand, grazing intensity had no effect on suppressing weed invasion. This contrasted work on perennial ryegrass under temperate conditions where high grazing intensity increased the persistence of tropical invading species at the expense of perennial ryegrass (Weeda & During 1987). For the sub-tropical conditions of South Africa, therefore, low grazing frequency, particularly during summer, must be applied to perennial ryegrass pastures to help reduce weed invasion.

Increasing levels of applied N (up to 600 kg ha^{-1}) increased root OM per unit volume of soil in the top 5 cm of the soil, while a corresponding decrease in root OM per unit volume of soil was observed in the 10 - 20 cm soil depth category. Although the evidence from the N trial is inconclusive as far as rooting depth is concerned, indications were that high levels of applied N stimulated root development in the upper soil layer (0 - 5 cm) at the expense of root development at greater depths (5 - 10 and 10 - 20 cm). Perennial ryegrass proved to be extremely shallow rooted, with approximately 75 % of the root mass in the top 5 cm of the soil.

The root system of perennial ryegrass continued to develop throughout the establishment year, with grazing defoliation effects becoming apparent only during the second year. A larger root system was encouraged by a low grazing frequency. Grazing intensity appeared not to affect root OM per unit volume of soil. It would appear, therefore, that defoliation frequency is more important than defoliation intensity in influencing root production in perennial ryegrass under sub-tropical conditions at Ukulinga. This is surprising since root growth is generally retarded when plants are defoliated. The greater the frequency and/or intensity of defoliation, the greater is the reduction in root growth (Christiansen & Svejcar 1988; Fulkerson *et al.* 1993). Fulkerson *et al.* (1993), working under sub-tropical conditions, reported lower root production in summer at more frequent cutting (every two weeks) than at less frequent cutting (every four weeks). On the other hand, Davidson and Milthorpe (1966) showed that the greater the level of defoliation intensity (cutting) applied to *Dactylis glomerata*, the longer it took for roots to regain their capacity to take up minerals.

Although the evidence was inconclusive as far as seasonal effects on root development were concerned, indications are that a larger root system develops in spring than in summer under sub-tropical conditions. This reflects the general pattern of root development for temperate conditions in New Zealand (Caradus & Evans 1977). These results would suggest that perennial ryegrass is in a weaker state (because it has a smaller root system) during summer than during spring and thus requires careful management over the summer period, particularly under sub-tropical conditions where summer temperatures are high.

As far as grazing management is concerned, the mail survey highlighted some management options to help enhance pasture survival. The period of absence of animals from the pasture during summer was identified as the most important grazing variable affecting pasture survival. Practical implications of these results are that perennial ryegrass requires adequate periods of recovery after grazing during summer (i.e. $\geq$ 21 days). For pure stands of perennial ryegrass, the length of the period of occupation also has an important effect on pasture survival. During summer and to a lesser extent during winter, long periods of occupation (e.g. seven days) by grazing animals have a negative influence on pasture survival. Such an influence could be minimized by reducing the period of occupation (e.g. $\leq$ 3 days) of grazing animals (e.g. by strip grazing or increasing the number of camps).

For perennial ryegrass with clover, the period of absence from the pasture during summer is also strongly related to pasture survival, as is, although to a lesser extent, the period of absence during spring/autumn. Although the period of occupation (during any season) was not identified as contributing meaningfully to pasture longevity, the length of the period of absence from grazing during summer, as in pure stands of perennial ryegrass, is extremely important.

Grazing intensity was not highlighted as an important contributor to pasture survival. The mail survey results suggest that periods of occupation by grazing animals and absence from the pasture are more important considerations than grazing intensity for perennial ryegrass pasture survival under the sub-tropical conditions of KwaZulu-Natal.

With respect to irrigation, the mail survey highlighted some principles which should be used to enhance pasture survival. A positive relationship exists between increasing the level of water applied and pasture survival in all seasons for perennial ryegrass (as pure or clover-based stands). For pure stands of perennial ryegrass, summer irrigation is an important variable contributing to pasture survival. For perennial ryegrass with clover, irrigation during spring/autumn is an important factor influencing pasture survival. The shallow rooting of this species emphasises the need to pay careful attention to irrigation scheduling.

For perennial ryegrass management under temperate environments, an understanding of the effects of grazing defoliation on tiller demography forms the basis of pasture management (e.g. Hunt & Brougham 1967; Korte *et al*. 1982; Davies & Thomas 1983; Thom 1991; Swift *et al*. 1993). Korte (1986) stated that, even for temperate environments, the importance of tillering has not been adequately elucidated. A major objective of the Ukulinga trial was, therefore, to provide an understanding of the mechanisms governing perennial ryegrass tiller demography under sub-tropical conditions. This would help provide a more objective basis for formulating grazing management programmes for local conditions as these management programmes are currently based primarily on principles developed for temperate conditions (Goodenough *et al*. 1991; Eckard 1993).

Total perennial ryegrass tiller densities declined during the summer periods and increased during the autumn, winter and spring periods. Seasonal fluctuations in total tiller density were lowest for those treatments infrequently defoliated (i.e. LFHI and LFLI). Frequent and intensive defoliation (HFHI), particularly during the summer periods, resulted in lower tiller densities than infrequent defoliation, regardless of the intensity level (LFHI and LFLI). This is in contrast to temperate conditions where perennial ryegrass tiller density tends to increase with frequent and intense defoliation (Grant *et al*. 1981; Korte *et al*. 1982; Baker & Leaver 1986; Korte 1986; Clark 1993b) and decrease with infrequent and lenient defoliation (Tainton 1974; Pineiro & Harris 1978; Grant *et al*. 1983; Lowe & Bowdler 1988). This suggests that low rather than medium to high defoliation frequencies impart a greater stability to perennial ryegrass tillers under sub-tropical conditions.

There was a tillering 'flush' from autumn to spring relative to the summer periods. This 'flush' was highest for spring, with a minor trough in winter, and was associated with high tiller appearance rates (TAR) and low tiller death rates (TDR) for this period. In terms of the Ukulinga study, these tillering 'flushes' from autumn to spring are considered important because they resulted in an almost doubling of tiller densities after the late summer period for most treatments. Tiller densities were low during the summer periods because the TAR were low while the TDR were high. Contrary to some of these results, low tillering rates for grazed perennial ryegrass swards during autumn have been reported for temperate conditions in New Zealand (Korte 1986; L'Huillier 1987), where little importance is placed on autumn tillering (Korte *et al*. 1985). On the other hand, studies conducted in the United Kingdom (Langer 1963; Garwood 1969) have identified periods of rapid tillering during both spring and autumn. Garwood (1969) reported that tiller numbers increased rapidly in autumn and again in late winter or early spring, and then declined until mid summer.

It has been established that for perennial ryegrass under temperate conditions, high frequency and intensity defoliations, whether by cutting or grazing, stimulates high TAR (e.g. Grant *et al*. 1981; Korte *et al*. 1982; Lowe & Bowdler 1988). High defoliation frequency and intensity accelerates the rate of tillering by increasing the rate of leaf appearance (Mitchell 1953; Davies 1981) and improving light penetration to the base of the sward (Grant *et al*. 1981; Davies & Thomas 1983). Under the sub-tropical conditions at Ukulinga, the general response of perennial ryegrass to frequent and intensive defoliation (HFHI and CG) was, at least initially, to also have high TAR. However, such defoliation decreased the tillering ability of perennial ryegrass after one and a half years and the treatment incorporating low defoliation frequency and high intensity (LFHI) emerged as the best grazing defoliation option enhancing TAR under these sub-tropical conditions. This result was most likely due to the enhanced plant and individual tiller vigour which was observed for low grazing frequency.

The seasonal pattern of tillering in perennial ryegrass is relatively unaffected by management under temperate conditions (Langer *et al*. 1964; Korte 1986; L'Huillier 1987). This was also observed for the sub-tropical conditions encountered at Ukulinga. However, TAR and TDR can be manipulated within a given season by defoliation. High frequency and intensity defoliations initially produced high TAR, but these were lower after one and a half years than in other treatments. On the other hand, high frequency and intensity defoliations consistently produced the highest TDR relative to other treatments. Generally, for the sub-tropical conditions experienced during the trial, the low frequency treatments (LFLI and LFHI) proved to be the most stable (in terms of tiller survival), particularly during the summer periods. This was presumably because the low frequency grazing enhanced both plant and individual tiller vigour. Overall, however, perennial ryegrass swards were more stable under our sub-tropical conditions (in terms of tiller survival), regardless of the defoliation management applied, during the cooler (autumn, winter and spring) than the warmer seasons (early to late summer). The cooler seasons for temperate environments are also reported to favour tiller survival (Thom *et al*. 1986; Thom 1991).

The survival of tillers originating during summer was poor in all treatments. Tiller survival during summer was, however, enhanced by adopting a low grazing frequency (LFHI and LFLI). Conversely, the potential to survive of tillers originating in autumn, winter and spring was good relative to those originating in summer. This was generally the case for all treatments; however, those frequently and intensively defoliated (HFHI and CG) had lower survival potentials than the less frequently and intensively defoliated (LFHI, MFMI, LFLI and HFLI) treatments. Overall, results showed that tillers arising in autumn, winter and spring were all important in maintaining perenniality, while those originating during the summer periods were not. Some of these results contradict the findings of earlier work conducted under temperate conditions. It is reported that tillers formed during spring are unlikely to survive the summer periods and most tend to die while still vegetative (Langer 1956; Hill & Watkin 1975).

In terms of reproductive tillering, irrespective of management applied, vegetative tillers originating in early summer and autumn become reproductive in spring the following year under sub-tropical conditions. Hill and Watkin (1975) showed a similar pattern of development in New Zealand. The period of reproductive tiller development for the sub-tropical conditions at Ukulinga was from August to October. This is approximately two months earlier than for perennial ryegrass pastures in new Zealand (Korte *et al.* 1984; Korte 1986; L'Huillier 1987). Generally, treatments incorporating low grazing frequency (LFLI and, to a lesser extent, the LFHI) had higher reproductive tiller densities than treatments incorporating high defoliation frequency (HFHI and CG).

As far as aerial tillering is concerned, work under temperate conditions has shown that higher aerial tiller densities occur in leniently grazed swards than in intensively grazed swards (Tainton 1974; Korte *et al.* 1987; L'Huillier 1987). Greater shading of vegetative tillers in infrequently and leniently defoliated swards has often been shown to promote aerial tillering (Hughes & Jackson 1974; L'Huillier 1987). Under the sub-tropical conditions at Ukulinga, treatments infrequently defoliated (LFLI and, to a lesser extent, LFHI) were also observed to have higher aerial tiller densities than treatments frequently and intensively defoliated (HFHI and CG). Overall, it is not believed that aerial tillers would contribute to the persistence of perennial ryegrass, either under temperate (Korte *et al.* 1987) or sub-tropical conditions.

Management model for perennial ryegrass

The findings of this study were used to construct a proposed management model for perennial ryegrass under sub-tropical conditions. Where definite management principles emerged, either from the mail survey or the field work, these were used in the construction of the management model. Where additional research work is still required or is totally lacking, the recommended principles of other published research were used. While a model for both pure stands of perennial ryegrass (Table 5.1) and perennial ryegrass-clover (Table 5.2) is proposed, detailed field work for perennial ryegrass-clover on grazing defoliation is still required.

Table 5.1 Proposed management of pure stands of perennial ryegrass

Management variables	Recommendation	Source
Soil fertility management:		
Phosphorus (P) (mg L^{-1})	$\geq$ 18	Manson *et al.* 1990
Potassium (K) (mg L^{-1})	$\geq$140	Manson *et al.* 1990
Acid saturation (%)	$\leq$ 10	Manson *et al.* 1990
N fertilizer:		
N application rate (kg N ha^{-1} a^{-1})	350 to 450	Manson *et al.* 1990 Eckard 1994 CHAPTER 4
Number split applications	$\geq$ 7	CHAPTER 2
Grazing defoliation management:		
Occupation during summer (days)	$\leq$ 3	CHAPTER 2
Occupation during spring/autumn (days)	$\leq$ 3	CHAPTER 2
Occupation during winter (days)	$\leq$ 3	CHAPTER 2
Absence during summer (days)	$\geq$ 21	CHAPTER 2 CHAPTER 3
Absence during spring/autumn (days)	18 to 28	CHAPTER 2 CHAPTER 3
Absence during winter (days)	28 to 35	CHAPTER 2 CHAPTER 3
Defoliation intensity in summer (cm)	approx. 10	CHAPTER 2 CHAPTER 3
Defoliation intensity in spring/autumn (cm)	approx.7.5	CHAPTER 2 CHAPTER 3
Defoliation intensity in winter (cm)	approx. 5	CHAPTER 2 CHAPTER 3
Irrigation management:		
Application in summer (mm $week^{-1}$)	approx. 22	CHAPTER 2
Application in spring/autumn (mm $week^{-1}$)	approx. 19	CHAPTER 2
Application in winter (mm $week^{-1}$)	approx. 19	CHAPTER 2
Frequency in summer	15-20mm every 4-5 days	Goodenough *et al.* 1991
Frequency in autumn/winter/ spring	20-25mm every 5-7 days	Goodenough *et al.* 1991
Additional management options:		
Season of establishment	Autumn	CHAPTER 2
Pasture renovation	sod-seeding (biennially)	CHAPTER 2
Defoliation by cutting	occasional	CHAPTER 2

Table 5.2 Proposed management of perennial ryegrass-clover

Management variables	Recommendation	Source
Soil fertility management:		
Phosphorus (P) (mg L^{-1})	$\geq$ 25	Manson *et al.* 1990
Potassium (K) (mg L^{-1})	$\geq$140	Manson *et al.* 1990
Acid saturation (%)	$\leq$ 1	Manson *et al.* 1990
N fertilizer:		
N application rate (kg N ha^{-1} a^{-1})	250	Manson *et al.* 1990 Eckard 1994 CHAPTER 4
Number split applications	$\geq$ 5	CHAPTER 2
Grazing defoliation management:		
Occupation during summer (days)	$\leq$ 3	CHAPTER 2
Occupation during spring/autumn (days)	$\leq$ 3	CHAPTER 2
Occupation during winter (days)	$\leq$ 3	CHAPTER 2
Absence during summer (days)	$\geq$ 21	CHAPTER 2
Absence during spring/autumn (days)	28	CHAPTER 2
Absence during winter (days)	18	CHAPTER 2
Defoliation intensity in summer (cm)	approx. 10	CHAPTER 2
Defoliation intensity in spring/autumn (cm)	approx. 8	CHAPTER 2
Defoliation intensity in winter (cm)	approx. 6	CHAPTER 2
Irrigation management:		
Application in summer (mm $week^{-1}$)	approx. 22	CHAPTER 2
Application in spring/autumn (mm $week^{-1}$)	approx. 22	CHAPTER 2
Application in winter (mm $week^{-1}$)	approx. 19	CHAPTER 2
Frequency in summer	15-20mm every 4-5 days	Goodenough *et al.* 1991
Frequency in autumn/winter/spring	20-25mm every 5-7 days	Goodenough *et al.* 1991
Additional management options:		
Season of establishment	Autumn	CHAPTER 2
Pasture renovation	sod-seeding (triennially)	CHAPTER 2
Defoliation by cutting	occasional	CHAPTER 2

Future research directions

The future research directions that are proposed here are directed mainly at addressing persistency related issues in perennial ryegrass in sub-tropical environments. These proposals stem directly from the review of the activities of perennial ryegrass farmers in KwaZulu-Natal (CHAPTER 2) and from areas of research conducted by the author (CHAPTER 3 and CHAPTER 4), where it is believed that further experimentation is required. These research directions are listed as follows:

1) The effects of grazing defoliation management on perennial ryegrass incorporating clover requires attention. There is evidence to suggest that the incorporation of clover may enhance pasture longevity and this requires quantification (CHAPTER 2).

2) The potential benefits of pasture renovation (either through sod-seeding, over-sowing or pasture aeration to reduce soil compaction) requires addressing. Evidence has emerged that these methods may significantly enhance pasture longevity (CHAPTER 2).

3) The potential benefits of incorporating mechanical defoliation (for forage conservation e.g. hay or silage) as part of the management programme requires addressing. There is a suggestion that such a practice may enhance pasture longevity (CHAPTER 2).

4) Future research addressing the effects of applied N should be based on the interaction between N and a number of different defoliation programmes. There is controversy regarding potential benefits of applied N to perennial ryegrass and it is believed that this controversy is related to the confounding of both the frequency and intensity of defoliation and N level (CHAPTER 4).

5) Future research addressing effects of applied N on perennial ryegrass should incorporate an economic analysis of animal production parameters (CHAPTER 4). Uneconomical animal production may preclude recommendations for high levels of N input based solely on plant parameters.

6) The recommendations for grazing defoliation based on a low frequency (and either low or high intensity) programme, particularly during summer, require testing in an animal production based system. Such a research programme will compliment the Ukulinga grazing trial (CHAPTER 3).

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APPENDICES

Appendix 2.1

Department Grassland Science
University of Natal
P.O.Box 375
Pietermaritzburg 3200
3 January 1994

Dear Sir

Perennial ryegrass postal survey - preliminary notice

I am currently involved with a PhD research trial (under supervision of Prof N.M. Tainton) on perennial ryegrass. A major objective of this trial is to establish ways of managing perennial ryegrass in order to enhance its longevity. As part of the trial I am conducting a postal survey of farmers in Natal who plant perennial ryegrass (either alone or in combination with clover) or who may have had some experience with this pasture.

I will be sending you a questionnaire on perennial ryegrass in about two weeks time. As there are no research data for this pasture species in South Africa, your cooperation in answering this questionniare will be very valuable and greatly appreciated. The questionnaire is designed in such a way that very little writing will be required on your part and it should not take you longer than 30 minutes to complete. You are also not required to furnish your name, thus any information you venture will be anonymous.

Thank you for taking time to read this letter and I trust you will look upon the questionnaire favourably.

Yours sincerely

Frank Mckenzie
(researcher)

Prof. N.M. Tainton
(supervisor)

Appendix 2.2

Department Grassland Science
University of Natal
P.O.Box 375
Pietermaritzburg 3200
10 January 1994

Dear Sir

Survey of perennial ryegrass growers in Natal

For many years, *Lolium multiflorum* Lam. (Italian ryegrass) has formed the basis of many intensive dairy systems and has increasingly been used for both fat lamb and beef production in South Africa. Italian ryegrass is high-yielding, but has the distinct disadvantage that it is short-lived. In addition, increased mechanisation costs have initiated a search for perennial grass species which can play the same role in the production systems, but which do not require annual re-establishment. At present, costs for annual re-establishment of ryegrass is in excess of R2800 per hectare.

If *Lolium perenne* L. (perennial ryegrass) is to successfully replace Italian ryegrass in local production systems, management programmes will need to be designed which will ensure its persistence in such systems. A research programme, designed to test the effects of different grazing management systems on the persistence of perennial ryegrass, is currently underway at the University of Natal. The questionnaire enclosed forms part of this study to help develop a grazing management system that will successfully enhance the longevity of perennial ryegrass. There is a general lack of information pertaining to perennial ryegrass in South Africa and your participation in this survey will therefore be appreciated. Please note that such participation in this regard is on a voluntary basis. Any information ventured will be treated as confidential and you will remain anonymous.

Answer the questions that follow by ticking the appropriate block. If you are unsure about a question, you may leave it out. If you have had previous experience with perennial ryegrass, alone or in combination with clover, and no longer use this pasture, then please also consider answering the questions. Once you have completed the questionnaire, please place it in the stamped addressed envelope and post it. Thank you for your cooperation.

Yours sincerely

Frank Mckenzie
(researcher)

Prof. N.M. Tainton
(supervisor)

QUESTIONNAIRE

(A) General considerations

1) Are you currently growing perennial ryegrass, or have you had experience with this pasture in the past and no longer utilise it?

- [ ] currently growing it
- [ ] previously utilised it
- [ ] have not grown it

2) Do you plant perennial ryegrass alone, or in association with clover?

- [ ] alone
- [ ] with clover
- [ ] both

3) What area do you have established to perennial ryegrass?

Ryegrass:
- [ ] 0 - 5 ha
- [ ] 5 - 10 ha
- [ ] 10 - 15 ha
- [ ] 15 + ha (specify) ____________

Ryegrass clover Mix:
- [ ] 0 - 5 ha
- [ ] 5 - 10 ha
- [ ] 10 - 15ha
- [ ] 15 + ha

4) What production system utilizes your perennial ryegrass?

Ryegrass:
- [ ] Dairy
- [ ] Beef
- [ ] Fat lamb
- [ ] Other (specify) ____________

Ryegrass clover mix:
- [ ] Dairy
- [ ] Beef
- [ ] Fat lamb
- [ ] Other

5) When do you establish your perennial ryegrass?

- [ ] Spring (specify month) ____________
- [ ] Autumn (specify month) ____________

(B) Climatic data

1) **What bioclimatic region is your farm located in?**

- [ ] (1) Coastal lowlands
- [ ] (2) Coastal hinterland
- [ ] (3) Mist belt
- [ ] (4) Highland to submontane
- [ ] (5) Montane
- [ ] (6) Upland (moist tall grassveld)
- [ ] (7) Riverine (Tugela)
- [ ] (8) Upland (dry tall grassveld)
- [ ] (9) Lowland to upland (Zululand)
- [ ] (10) Interior lowland
- [ ] (11) Arid lowland
- [ ] ** If in doubt, state nearest town: ______________

2) **What is your average annual rainfall?**

- [ ] 400 - 600 mm
- [ ] 600 - 800 mm
- [ ] 800 - 1000 mm
- [ ] 1000 - 1200 mm
- [ ] 1200 mm +

3) **What is your elevation above sea level?**

- [ ] 0 - 450 m
- [ ] 450 - 900 m
- [ ] 900 - 1400 m
- [ ] 1400 - 1950 m
- [ ] 1950 - 3400 m

(C) Pasture production

1) **Before establishing perennial ryegrass, do you have a soil test conducted of the area?**

- [ ] Yes
- [ ] No
- [ ] sometimes

2) **Do you reduce acid saturation in your soil by applying lime?**

- [ ] Yes (specify soil acid saturation level) __________
- [ ] No

3) Do you fertilize with phosphorus (P) and potassium (K)?

P: Yes ☐ No ☐ K: Yes ☐ No ☐

4) If yes to (3), do you aim to maintain specific soil levels of P and K?

☐ Yes (specify soil levels) ______ ppm K ______ ppm P
☐ No

5) What level (in kgN/ha) of nitrogen do you apply annually to your perennial ryegrass or ryegrass clover mixture?

Ryegrass:
☐ 0 - 100
☐ 100 - 200
☐ 200 - 300
☐ 300 - 400
☐ 400 + (specify) __________

Ryegrass clover mix:
☐ 0 - 100
☐ 100 - 200
☐ 200 - 300
☐ 300 - 400
☐ 400 +

6) How many split applications (dressings) of nitrogen are administered annually?

Ryegrass: __________
Ryegrass clover mix: __________

7) Indicate how long after establishment your pasture requires some form of renovation.

Ryegrass:
☐ 1 year
☐ 2 years
☐ 3 years
☐ 4 years
☐ 4+years (specify) __________

Ryegrass clover mix:
☐ 1 year
☐ 2 years
☐ 3 years
☐ 4 years
☐ 5+years

8) If you do practice some form of partial pasture renovation/rejuvenation, indicate how you do this.

Ryegrass:
☐ oversowing (broadcast seed application)
☐ sod seeding (drilling seed into the pasture)
☐ other (specify) __________

Ryegrass clover mix:
☐ oversowing
☐ sod seeding
☐ other (specify) __________

9) Indicate how long your pasture survives before requiring complete re-establishment.

Ryegrass:
- [ ] 1 year
- [ ] 2 years
- [ ] 3 years
- [ ] 4 years
- [ ] 5 years
- [ ] 6+years (specify) ____________

Ryegrass clover mix:
- [ ] 1 year
- [ ] 2 years
- [ ] 3 years
- [ ] 4 years
- [ ] 5 years
- [ ] 6+years

10) Do you have a fixed or supplementary irrigation schedule?

- [ ] fixed
- [ ] supplementary

11) What level of irrigation do you generally apply on a weekly basis?

Ryegrass:

summer	winter	spring/autumn
[ ] 15 - 20 mm	[ ] 15 - 20 mm	[ ] 15 - 20 mm
[ ] 20 - 25 mm	[ ] 20 - 25 mm	[ ] 20 - 25 mm
[ ] 25 - 30 mm	[ ] 25 - 30 mm	[ ] 25 - 30 mm

Ryegrass clover mix:

summer	winter	spring/autumn
[ ] 15 - 20 mm	[ ] 15 - 20 mm	[ ] 15 - 20 mm
[ ] 20 - 25 mm	[ ] 20 - 25 mm	[ ] 20 - 25 mm
[ ] 25 - 30 mm	[ ] 25 - 30 mm	[ ] 25 - 30 mm

12) Does the level of pasture production decline in the second year after establishment?

Ryegrass:
- [ ] Yes
- [ ] No

Ryegrass clover mix:
- [ ] Yes
- [ ] No

13) What is your estimated level of production (in tonnes dry matter per ha) during the first year of establishment?

Ryegrass:
- [ ] 10 - 12 t/ha
- [ ] 12 - 14
- [ ] 14 - 16
- [ ] 16 - 18
- [ ] 18 + (specify) ____________

Ryegrass clover mix:
- [ ] 10 - 12 t/ha
- [ ] 12 - 14
- [ ] 14 - 16
- [ ] 16 - 18

- [ ] 18 + (specify) ____________

14) What is your estimated level of production (tDM/ha) during subsequent years after establishment?

Ryegrass:
- ☐ year 2 ____________
- ☐ year 3 ____________

Ryegrass clover mix:
- ☐ year 2 ____________
- ☐ year 3 ____________

15) Do you obtain meaningful production after four years?

Ryegrass:
- ☐ Yes (specify) ________________
- ☐ No (specify) ________________

Ryegrass clover mix:
- ☐ Yes (specify) ________________
- ☐ No (specify) ________________

16) If a reasonable level of production could be maintained in the second year following establishment, would you consider it viable to treat perennial ryegrass as a biennial pasture (ie. re-establish every two years) rather than plant annual ryegrass each year?

Ryegrass:
- ☐ Yes
- ☐ No

Ryegrass clover mix:
- ☐ Yes
- ☐ No

(D) Pasture utilization

1) Indicate whether the pasture is grazed, cut as conserved feed (eg. hay or silage) or both.

Ryegrass:
- ☐ 100 % grazed and 0 % cut
- ☐ 75 % grazed and 25 % cut
- ☐ 50 % grazed and 50 % cut
- ☐ 25 % grazed and 75 % cut
- ☐ 0 % grazed and 100 % cut

Ryegrass clover mix:
- ☐ 100 % grazed and 0 % cut
- ☐ 75 % grazed and 25 % cut
- ☐ 50 % grazed and 50 % cut
- ☐ 25 % grazed and 75 % cut
- ☐ 0 % grazed and 100 % cut

2) What form of grazing do you employ?

Ryegrass:
- ☐ rotational
- ☐ continuous
- ☐ strip
- ☐ other (specify) ______________

Ryegrass clover mix:
- ☐ rotational
- ☐ continuous
- ☐ strip
- ☐ other (specify) ______________

3) If rotationally grazed, do you:

Ryegrass:
- ☐ use a set rotation year round?
- ☐ adapt the rotation to match growth in each season?

Ryegrass clover mix:
- ☐ use a set rotation year round?
- ☐ adapt the rotation to match growth in each season?

4) Give an indication of the grazing frequency (rotation) you apply.

Ryegrass:	Summer	days in?______	days out?______
	Winter	days in?______	days out?______
	Spring/Autumn	days in?______	days out?______
Ryegrass clover mix:	Summer	days in?______	days out?______
	Winter	days in?______	days out?______
	Spring/Autumn	days in?______	days out?______

5) Give an indication of the grazing intensity (height of defoliation) you apply.

	Summer	Winter	Spring/Autumn
Ryegrass:	☐ < 5cm ☐ 5-10cm ☐ > 10cm	☐ < 5cm ☐ 5-10cm ☐ > 10cm	☐ < 5cm ☐ 5-10cm ☐ > 10cm
Ryegrass clover mix:	☐ < 5cm ☐ 5-10cm ☐ > 10cm	☐ < 5cm ☐ 5-10cm ☐ > 10cm	☐ < 5cm ☐ 5-10cm ☐ > 10cm

General comments

1) Do you have any general comments about the advantages and disadvantages of perennial ryegrass in your system compared to the use of annual ryegrass?

Advantages of perennial ryegrass: ____________________

Disadvantages of perennial ryegrass: ____________________

2) Would you consider a system of:

using clover as a base and oversowing some perennial ryegrass into it each year? ____________________

oversowing perennial ryegrass each autumn with oats? __________

3) Any other comments you may wish to make?

Appendix 2.4

Department Grassland Science
University of Natal
P.O.Box 375
Pietermaritzburg 3200
15 February 1994

Dear Sir

Survey of perennial ryegrass growers in Natal (reminder)

This note serves to thank those of you who have returned your questionnaires and to remind those who have not yet done so (in the interest of producing a more conclusive report on perennial ryegrass management) to please consider returning the questionnaire. Just in case you have misplaced the first questionnaire, I have enclosed a second one which you may discard if you have already returned the first one. I plan to start analyzing these data at the end of March this year.

So far, the response to the perennial ryegrass questionnaire has been very good. To date, I have already received over 40% of the questionnaires I sent out. The information contained in these questionnaires will, I believe, help isolate problems concerning persistency of perennial ryegrass in South Africa and highlight ways of successfully managing perennial ryegrass.

Anyone requiring a report back on the results of this investigation can request one by using the stamped addressed envelop enclosed. I will then gladly supply a detailed summary of the research findings of this on-farm investigation as soon as I complete the appropriate analyses.

To those farmers who indicated that I should contact them, thank you for your keen interest in this subject. I will be in touch some-time in the near future.

Thank you for your time and effort.

Yours sincerely

Frank Mckenzie
(researcher)

Prof. N.M. Tainton
(supervisor)

Appendix 2.5

I am interested in the results of the perennial ryegrass survey. Please send me a copy of these as soon as they become available.

NAME : ______________________________

ADDRESS : ______________________________

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